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Ambient Lighting Integrated Assistance System

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Mestrado Integrado em Engenharia Informática e Computação

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July 22, 2015

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Abstract

Nowadays a lot of knowledge about the effects of lighting on human health and mood exists and is still growing. However, this knowledge isn't generally being put into practice. Light is something that surrounds us every day and everywhere, therefore knowledge of it can also be used every day from dawn to dusk and everywhere like home, schools, health facilities, workplace or even outside.

Artificial lighting is harmful if used incorrectly, affecting the normal circadian rhythm's pace and therefore several biological properties. Elderly people are further affected by artificial lighting since they prevail more time inside buildings, under the effect of artificial lighting, and have usually more health problems.

This project was developed on Fraunhofer Portugal facilities and integrated in the SmartCompanion project, which has the objective to improve elderly's life. SmartCompanion is a launcher for Android smartphones that, for example, allows the elder to request help from his caregiver and detects his falls.

In the sense of enhancing artificially made environments, the main goal of this project is to develop a system able to provide a soother, safer and self–healing environment for elderly people and their caregivers. Shortly, the system should: 1) React to external events like elderly' falling detection and help requests, using the light bulbs to visually notify the caregiver of possible problems with the elderly. 2) React to SMS and phone call receptions, performing visual notifications to help elderly people with hearing impairments. 3) Perform periodic updates on the lights to promote the normal pace of the circadian rhythm.

This work encourage the usage and development of lighting and lighting systems in a smarter and deliberated manner with not only illumination concerns, but also biological one.

Resumo

Atualmente, embora em crescimento, existe algum conhecimento sobre os efeitos da luz na saúde e bem-estar do ser humano. No entanto, geralmente, este conhecimento não está a ser posto em prática. A luz é algo que nos rodeia todos os dias e em qualquer lugar e portanto conhecimento sobre esta pode também ser utilizado todos os dias, a qualquer hora e em qualquer lugar, por exemplo em casa, nas escolas, em instituições de saúde, locais de trabalho e até no exterior.

A luz de origem artificial é prejudicial se for usada incorretamente, afetando a regulação natural do ritmo circadiano e portanto vários parâmetros biológicos. Um grupo que é especialmente afetado com este problema são os idosos, pois estes normalmente permanecem mais tempo dentro de edifícios, sobre o efeito de luzes artificiais e têm mais problemas de saúde.

Este trabalho foi desenvolvido nas instalações da Fraunhofer Portugal e integrado no projeto SmartCompanion que tem como objetivo melhorar a vida do idoso. O SmartCompanion é um *launcher* para *smartphones* Android que, por exemplo, permite ao idoso pedir ajuda ao seu cuidador e detetar as suas quedas.

No sentido de melhorar os ambientes artificialmente iluminados, o principal objetivo deste trabalho é o desenvolvimento de um sistema capaz de fornecer, ao idoso e ao seu cuidador, um ambiente otimizado, mais seguro e que promova as capacidades de autorregulação do idoso. De forma resumida, o sistema deve: 1) Reagir a eventos externos como a deteção da queda ou pedidos de ajuda do idoso, utilizando as luzes para notificar visualmente o cuidador de possíveis problemas com o idoso. 2) Reagir à receção de SMS e chamadas telefónicas, realizando notificações visuais para auxiliar idosos com problemas auditivos. 3) Executar atualizações nas luzes periodicamente, de forma a promover o normal funcionamento do ritmo circadiano.

Este trabalho incentiva o uso e desenvolvimento de luzes e de sistemas de iluminação de uma forma mais deliberada e inteligente, com interesses não só na iluminação, mas também nas reações que esta provocará no ser humano.

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Pedro Miguel de Almeida

“A minha média subiu quando eu pensei,
«hum, secalhar devia deixar de ir às aulas»”

Cristiano Alexandre Rodrigues

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Abbreviations

API	Application Program Interfaces
ANS	Autonomic Nervous System
CCFL	Cold Cathode Fluorescent Lamp
CRT	Cathode Ray Tube
EMR	Electromagnetic Radiation
GUI	Graphical User Interface
HTML	HyperText Markup Language
HTTP	Hypertext Transfer Protocol
IOL	Intraocular Lens
IPRGCs	Intrinsically Photosensitive Retinal Ganglion Cells
JSON	JavaScript Object Notation
LED	Light-Emitting Diodes
MVC	Model-View-Control
NoSQL	Not Only SQL
NPM	Node Package Manager
OS	Operating System
PDT	Photodynamic Therapy
PNS	Parasympathetic Nervous System
pRGCs	photosensitive Retinal Ganglion Cells
SAD	Seasonal Affective Disorder
SCN	Suprachiasmatic Nucleus
SMS	Short Message System
SNS	Sympathetic Nervous System
UI	User Interface
UV-B	Ultra Violet type B
XML	Extensive Markup Language

Chapter 1

Introduction

This chapter introduces lighting and circadian rhythm as a study object and a mean to provide better ambient and healing conditions for people. It is introduced also the lack of concern about lighting in human health and well-being as the problem, followed by the goal and expected results from the solution.

1.1 Context

Light is essential for all kinds of living forms. Light has an influence on animals and plants day-by-day life, setting their biorhythms. In humans, it is proved that light has an influence on people's health, vitamin D production, mood, depression, fatigue, alertness, among others [AJ06]. However, how light influences people and how far humanity can use it on their advantage, isn't still fully understood.

Light is an electromagnetic radiation and it can have several wavelengths, resulting in different colors. Since early times, many theories of human exposure to colored radiation exist and stayed in use in traditional medicine. Despite not being considered scientifically proved at that time, several theories persisted to modern times where some of them are now accepted scientifically and are used in modern medicine. Others are now being intensely studied using modern technologies and knowledge.

Circadian rhythm is a biological rhythm that makes part of human's daily cycle. The main stimulus of circadian rhythm is the exposure and reception of light in our eyes and skin. It is known that circadian rhythm affects several physiological and psychological parameters of humans. Circadian rhythm and light exposure have the ability to enhance or disrupt melatonin production, which itself, alters among other things, energy, alertness and sleepiness levels. Several studies, with consistent data, even concludes that circadian rhythm has a weight on cardiovascular diseases, cancer, pain relief and others exposed in this report.

Philips Hue is a system that allows the manipulation of several lighting parameters and the creation of visual notifications.

Therefore, a tool that provides to the user not only the ability to control of several lighting characteristics like color and intensity, but also an automatic self-healing and well-being environment with color and circadian rhythm concerns, should be useful.

Figure 1.1: Philips Hue lighting system. Image from [App15]

Fraunhofer Portugal is a private non-profit association with the goal to enhance social well- being and improve quality of life of its end-users. The major development focus of Fraunhofer Portugal is elderly people. Fraunhofer Portugal developed a large number of sensor based solutions in order to make elderly's life easier and safer through technology-driven assistance living. One of Fraunhofer's projects is called SmartCompanion, an Android launcher specially designed to meet seniors' needs like preventing isolation while promoting autonomy, quality of life and health monitoring [Por13]. This work was developed on Fraunhofer Portugal facilities and integrated on the SmartCompanion project with the objective of providing visual notifications from falls or other events like incoming calls or medication alarms, as well as through an automatic ambient lighting system, provide a self-healing environment.

1.2 The problem and its characterization

Artificial lighting usually doesn't take into consideration human health in terms of circadian rhythm and colored lighting effects. A visual notification system for assisted living with concerns about the well-being and biological effects of lights is something that should be useful. In addiction artificial light without this deliberation may cause unwanted effects.

Many ancient theories survived up to the present day about certain color radiations affecting our body and mind, some of them more credible and scientifically based than others. Despite some theories had already been accepted and in use in modern medicine, most of them are still waiting for being studied and approved or discarded.

Other studies, more scientific, about circadian rhythm exist. In fact, many of these studies are relatively recent and emphasize the curiosity and interest science currently has on this specific subject. Nevertheless, many of these studies were done in a very specific situation or with small samples, concluding that further investigation is still missing.

1.3 Goals

This work aims to provide a personalized wireless ambient lighting for assistive environments. The main idea is the usage of ambient lighting as a communication channel and as a health support system. Knowledge of circadian rhythm and colored lighting is used to provide an improved self-healing environment. Other features include the reaction to external events captured by sensors, changing the lighting status in order to serve as a visual communication and notification channel, readily understood. The development of such a tool is composed by the development of 4 essential sub-parts: 1) Android application that allows the user to define settings such as types of external events and their visual notifications, as well as the activation of predefined lighting configurations; 2) Web application for programming complex user defined lighting scenes and configurations; 3) Web server that provides the services necessary for the user, getting and storing user settings and lighting status as well as command light bulbs actions from external events or circadian rhythm updates, 4) Database where all the user defined settings and lighting status are stored.

In the future, the tool can also allow to put in practice and test existing theories and studies about lighting, colors and circadian rhythm effects on humans.

1.4 Expected benefits with the solution of the problem

With ambient lighting integrated assistance system, it is expected to promote home as a healing, safe, enjoyable and integrated living environment. The promotion of circadian rhythm regulation and colored lighting effects for living environments should provide a self-healing and improved ambience. Besides, visual notifications should allow an integrated ambient system as well as a notification channel for hearing impairments, so they can be aware of audible notifications from smartphones for example.

This system can also contribute, in the future, to an increment of research on the healing capabilities of all kinds of visible radiation and circadian rhythm, as well as improve quality of studies in this area, providing a tool capable to create several types of ambiences and dynamic lighting. It is likely that with additional and improved technological conditions that this work provides, as well as increased knowledge in the area, results on new solutions and treatments to modern days' issues could arise.

1.5 Structure and organization of the document

During this document, all the work performed will be presented and discussed.

In this first chapter an introduction and description of the document, with its goals, expected benefits and context, is done.

The second chapter is a literature review of the context of the project. It details the light and color properties, its healing effects, its effects on the circadian rhythm and finally, the circadian rhythm effects on people.

In the third chapter, a technological overview of several technologies relevant to the project are presented. In this chapter is also covered the Philips Hue System and similar projects.

The chapters 4, 5 and 6 refer to the development of the system. In the chapter 4, the solution, to solve the problem of the project and to fulfill it's objectives, is presented and detailed. In this chapter, it is also covered some key concepts, requirements, technological assignment, user stories and some usage scenarios.

In the chapter 5 the system developed is detailed. It is shown, for each module, the architecture, some explanations and implementation details.

In the chapter 6 the results obtained are presented. It is displayed how the several parts of the system interact with each other and with the user. Some images of the system are shown in order to illustrate the final product. In this chapter we cover also the usage of a remote API in order to overcome some project constraints.

In the last chapter, the conclusions of the system developed are detailed. The accomplished objectives are presented together with the development of this work and some future work proposals in order to further improve the final system.

Chapter 2

Light and its effects

In this chapter the properties of light are covered initially, followed by a description of some healing properties of colored lighting with several ancient time theories and scientific studies about them. Circadian rhythm, his biological properties on human body, and his effects on humans are also covered in this chapter.

2.1 Light

Light makes part of animal and plant life. It's essential for continuity and sustainability of all kinds of life.

Both animals and plants have what is called a circadian rhythm. This circadian rhythm is a biological cycle that repeats approximately every 24–hours and that, in both cases, the main stimulus is light. Studies show that light can improve human health, mood, depression, fatigue, alertness, etc. and also that it's possible to control the body's circadian system [AJ06].

Light is an electromagnetic radiation (EMR) in a wavelength interval that, is usually visible, but can include some invisible wavelengths (infrared, ultraviolet). Light's source can be natural or artificial.

The properties of visible light are intensity (or illuminance with the symbol lx), propagation direction, polarization and wavelength that include the range from 400 nanometers to 700 nanometers. There are some differences about natural and artificial lights. For example natural light has a more complex spectrum of wavelengths from visible to invisible while artificial light has a narrower range of wavelengths.

Light is already being used in different ways for therapeutic applications, such as the treatment of seasonal affective disorder (SAD), certain sleep problems, depression and jet lag [mag14].

2.1.1 Colored Light

Color is a visual perception obtained by visible light. The colors differ from each other by their wavelength (nm) or frequency (THz), as shown in Figure 2.1. The same wavelength light can appear as a different color, depending on the light intensity, for example orange–yellow in low–intensity is perceived as brown.

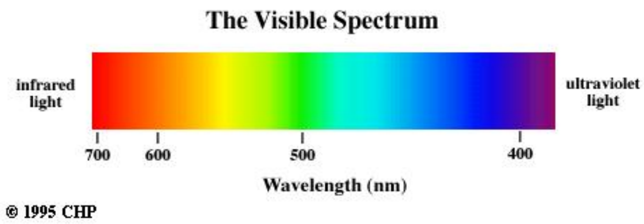

Figure 2.1: The visible Spectrum and his wavelengths. Image taken from [Vir15]

On objects, the perceived color is the result of light absorption, reflection and emission of certain wavelengths.

2.1.2 Vitamin D

Vitamin D is a chemical that can be acquired by diet or by skin exposure to Ultra Violet type B (UV–B). In the case of skin exposure, the natural procedure is to expose bare skin to sunlight, then the liver and kidney are responsible to activate it through enzymatic conversion.

Vitamin D enhances the calcium and phosphorus absorption in the bones, so the benefits of vitamin D are consensual in terms of bone health, however any other benefits are not clear [RMA+11]

2.2 Healing with color

For many years the scientific community refused to accept color medicine for medical practice. It is considered pseudoscience and it's mainly used in traditional medicine [AR05]. However, over the years new treatments were accepted and discovered. In the late 90's it was discovered that exposure to blue light was a cure for neonatal jaundice, a disease found in two thirds of premature babies that, in some cases, can be fatal. Now this technique, called Phototherapy it's the main treatment for neonatal jaundice and can be administrated through white, blue, turquoise and green wavelengths [Han14]. Photodynamic Therapy (PDT) is another example, in which light is used to kill microbial cells. It is mainly used for acne but the expansion of this method is happening to treat other diseases and even cancer patients [Pas93].

2.2.1 Sympathetic and Parasympathetic nervous system

The Autonomic Nervous System (ANS) also named involuntary nervous system is responsible for the regulation of the unconscious actions of the body. It is divided by the Sympathetic Nervous System and by the Parasympathetic Nervous System.

The Sympathetic Nervous System (SNS) is responsible for "Fight-or-Flight" actions. These actions are the several responses that the body performs automatically for survival in case of harmful events, fights or dangers. The body responses include acceleration of heart and lungs, constriction of the blood vessels except for muscles where they dilate with the increase of blood pressure, burn of fat to obtain energy, among others. In terms of psychological responses, this state is associated with anxiety and aggression [COFF10]

The Parasympathetic Nervous System (PNS) is the complement of the Sympathetic Nervous System. Is responsible for “rest-and-digest” or “feed and breed” actions like salivation or digestion [McC07]

It is believed that different areas of the brain respond and react to different colors (wavelengths) of radiation, interacting differently with the endocrine system to increase, decrease and even to start or stop hormonal production [AR05]. With the improvements of technology and medicine, it is highly probable to find more correlations between wavelengths of radiation and the human response. In 1991, Dr. Jacob Lieberman published the book *Light: Medicine of the Future* [Lib90] about this correlation. He pointed out that only in current times we are accepting traditional oriental knowledge used in ancient times in Egypt, Greece, China and India [AR05] to modern medicine. In this book can be found a digest and the results of several studies on this subject.

Figure 2.2 shows some oriental knowledge acquired since ancient times. A correlation of colors and body areas is shown, suggesting that these theories should be further studied and tested.

Until this date, the following content represents some knowledge acquired about this specific subject.

Blue and red colors are the most investigated [JYS12], and several studies established a relationship between blue and red colors to the ANS, where red color stimulates the SNS and the blue wavelengths stimulates the PNS. This means that red light increase blood pressure, pulse rate, respiration rate, eye–blink rate, excitement and increase of tension. The opposite happens with the Blue light. A feeling of relaxation is produced as well as a decrease of blood pressure, less anxiety and less hostility.

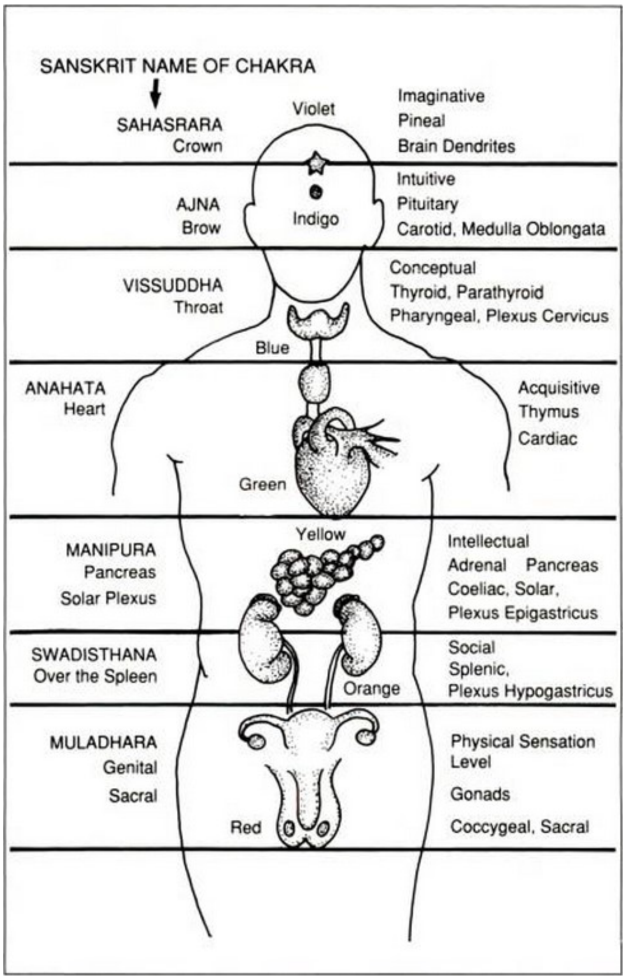

Figure 2.2: Link between chakra, color and body areas. Image taken from *Light: Medicine of the Future* [Lib90]

A report about the effect of red light on migraines show a method where the usage of goggles that emitted flashing red light at patients' eyes stops migraines [Lib90]. The patients could adjust the frequency and intensity that the red light is emitted. Results show great success, especially at high frequency and intensity. Other studies were made that show red light as a treatment for cancer, constipation and healing wounds [AR05].

Relative to blue, a study concerning the hypothesis of short wavelengths to ease pain was published [McD82]. The context of the study is pain relief for rheumatoid arthritis of 60 middle–aged women. The method used was the exposure to blue light in the subjects' hands up to fifteen minutes. Results show that most subjects reported a reduction of pain that is directly proportional to the duration of exposure. Blue light can be used likewise for healing injured tissue, preventing scar tissue, burns and lung conditions [AR05].

Another study about the several wavelengths concludes that the colors that can increase blood pressure, pulse rate and respiration rate is yellow, followed by orange and red. On the other side, the colors that more decrease these vital signs are blue and then green. [Lib90]

Table 2.1 resume the conclusions of the several studies analyzed. The meanings of the symbols are: +++ Maximum increase; ++ High increase; + Increase; - Decrease; -- High decrease.

Table 2.1: Resume of conclusions from several studies analyzed.

Color	**Physiological**	**Psychological**
Blue	-- Blood Pressure -- Pulse Rate -- Respiration Rate Treat. Neonatal Jaundice Pain relief Treat. Healing tissue	+ Relaxation - Anxiety - Hostility
Green	- Blood Pressure - Pulse Rate - Respiratory Rate	
Yellow	+++ Blood Pressure +++ Pulse Rate +++ Respiration Rate	
Orange	++ Blood Pressure ++ Pulse Rate ++ Respiration Rate	
Red	+ Blood Pressure + Respiratory movements Stop Migraine Treat & Prevent cancer Healing wounds	+ Anxiety

An American Journal article of acupuncture exposes the case of Dr. Dinshah Ghadiali. Dinshah was born in India but is an American citizen. At 24 years old, he cured his first patient using lighting radiation. After that he dedicated his life to understand phototherapy using physics and mathematics as a background [Coc99]. He established a relation between radiation wavelengths and human organs and how the human body responds to different frequencies. Figure 2.3 shows some conclusions of his work [Eis01].

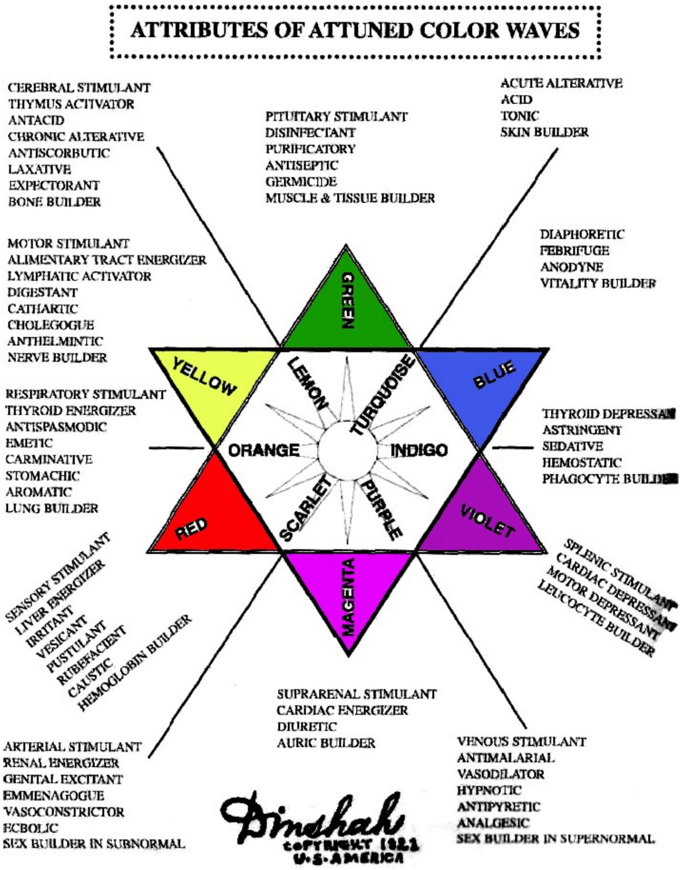

Figure 2.3: Relation between color and body. Image taken from [Tro01]

Despite colors' healing effects are subject of studies since 2000 BC [AR05], many contradictory conclusions still remain. It is required much more studies and effort to progress and find practical and scientific conclusions that mankind can use in their benefit.

2.3 Circadian Rhythm on humans

Circadian Rhythm is a natural biological clock that is inherent not only for humans, but also for other animals and even plants. It is noticeable that energy, alertness and sleepiness levels change throughout the day. It is known that the major stimulus that regulates the circadian rhythm is light. The main light stimulus that all animals and plants are exposed is sunlight. Naturally sunlight changes from dawn to dusk, and this change affects our circadian rhythm that adjusts energy, alertness and sleepiness levels.

In the following sections it is exposed not only the relationships between light, circadian rhythm and biological responses but also some related health issues that studies from this subject conclude.

Some other effects of the circadian rhythm interference are the impairment of the immune system function, and possibly some cardio metabolic consequences such as type 2 diabetes, metabolic syndrome, obesity, and heart disease [Kre13]

2.3.1 How it works

Light is received in the eyes, more specifically by the retina. The reception of the light (or lack of reception) is communicated to the suprachiasmatic nucleus (SCN) of the hypothalamus in the brain. In the SCN, if the information received indicates that there isn't light, the SCN will communicate the pineal gland to produce melatonin. On the other hand, if retina receives light, the SCN will indicate the pineal gland to not produce melatonin. This melatonin then is transported to all parts of the human body containing "time" information [AJ06].

The reception of the light by the retina is captured by rods and cones. Rod cells are located on the outer edges of the retina and are responsible for peripheral vision. These cells are more light sensitive than cone cells and almost exclusively responsible for night vision. Cone cells on the other hand, require 100 times more photons to be activated and are responsible for color vision. There are 3 types of cone cells in the human eye, like those shown on figure 2.4: S–cones (short wavelengths), M–cones (medium wavelengths) and L–cones (long wavelengths).

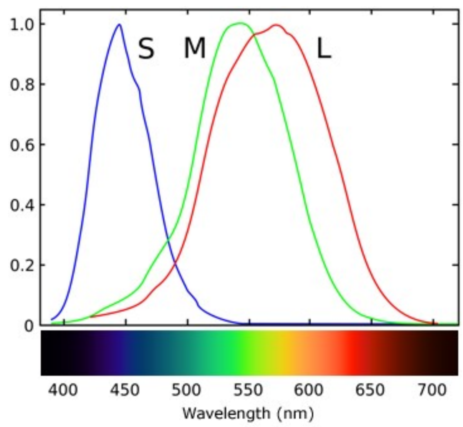

Figure 2.4: Cones sensitiveness by wavelengths. Image taken from [Irr00]

Intrinsically photosensitive Retinal Ganglion Cells (ipRGCs) or photosensitive Retinal Ganglion Cells (pRGCs) are a type of nerve cells in the retina that mold a non–image forming visual system [RGD13], this means that the result is not an image but a synaptic response from cones' and rods' inputs. These cells respond over the long term of light exposure, giving as a result a stable representation of ambient light intensity. IpRGCs contribute to pupillary control and release of melatonin from the pineal gland through the SCN [RGD13].

Melatonin can be present in different levels, and it affects the activity and energy levels. Several studies show that if during the day the amount of light is lower than it should be, it causes feelings of depression and sleepiness [AJ06], since a high level of melatonin causes drowsiness. Also a low level of melatonin is associated with a state of alertness [LMAV01, ET02]. However, the effects of lighting are not completely universal, mood changes can diverge from person to person [BHH03].

It is also known from several studies that short wavelength lights (around blue) are the ones with the biggest effect on melatonin suppression. Figure 2.5 shows the different sensitivity levels to wavelength and also that the wavelength more effective in melatonin suppression is around 464 nm [BHG+01] which represents the indigo color.

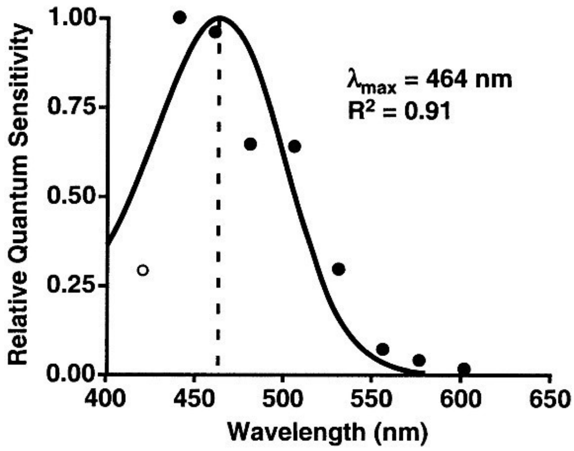

Figure 2.5: Eye sensitivity to different wavelengths and max sensitivity is at 464nm (Indigo color). Image taken from [BHG+01]

Another study [SWLC13] that support this conclusion is summarized in Figure 2.6. Different reactions, translated as melatonin levels, from exposure to 460nm (indigo) and to 555nm (green) monochromatic light can be seen.

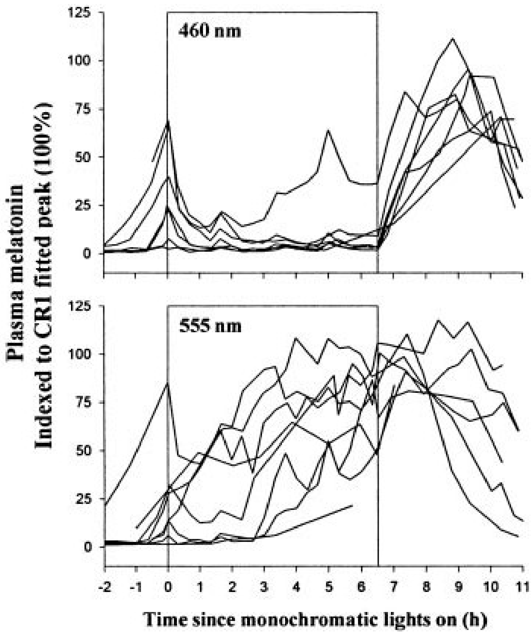

Figure 2.6: Difference between blue exposure (460nm) and green exposure (555nm) on melatonin production. Image taken from [SWLC13]

2.3.2 Circadian System in elderly people

During aging, the human lens suffers transformations. It is common to notice a yellower appearance of elderly people's eyes. This is caused by 2 reasons: the first is that with aging the normal pigment deposition increases. The second reason is that the average lens density increases linearly between 20 and 60 years old. However the increase is doubled for ages above 60 [PSL87]. These two factors beyond the yellowing factor, causes an increased filtering of short–wave radiations (violet, blue and some green) which itself causes a decrease of S–Cone (short–wavelength) cells sensitivity [EFKM87]. The lack of S–Cone sensitivity has a direct impact on melatonin suppression. This can be the cause of sleep, circadian rhythm and body rhythms turbulence. However the effects of lack of sensitivity of S–Cone on the elderly are still to be studied [HMTS05].

Many seniors who have done intraocular implant lens (IOL) have reported that the world looks much more bluer after the surgery [Cha03]. This causes the blue sensitivity to rise to youthful levels because of the property of the lens that transmits high amounts of short–wavelengths. The effects of IOL surgeries on seniors' circadian rhythm are still to be fully understood [Cha03].

2.3.3 Cardiovascular System

The cardiovascular system can be linked with the circadian rhythm since several parameters of this system like heart rate, heart rate variability and blood pressure had been related to circadian rhythm. Many issues associated with these parameters, for example, coronary artery disease, sudden cardiac death, atrial and ventricular arrhythmias as well as stroke have been extremely investigated and have been found connections with the circadian rhythm. For prevention, diagnosis and treatment of cardiovascular diseases, several studies conclude that circadian rhythm is a parameter that should be taken into account and there are still a lot of things we can learn from it [GS03].

2.3.4 Depression

Several studies suggested that artificial light between 2.500-10.000 Lux - around cloudy day and full daylight [Sch10], is effective in reducing depression on patients and that it's as effective as natural light [AJ06]. Another interesting indication is that isn't just the production of melatonin that maters, the time is also a major concern because the melatonin's effects are different throughout the day. For depression reduction, morning lighting is more effective than in the evening [AJ06].

2.3.5 Preterm infants

Other studies were made to test lighting cycle vs normal lighting. On an intensive–care unit for preterm infants it was shown that infants with cycled lighting had greater gain weight and spent less time on the ventilator and on phototherapy than preterm infants with normal lighting [AJ06].

2.3.6 Breast Cancer

A study published by Journal of Pineal Research discusses the possibility of cancer–cell growth caused by circadian disruption through light-at-night exposure. The study concluded that melatonin, through enzymatic processes, reduces the activation of cell proliferation and reduce cancer risk. The disruption of melatonin production at night by artificial light exposure is associated with higher risk of breast cancer. This is a problem particularly important for night shift workers [BHD+11]

2.3.7 Pain

A study was done with the purpose of testing if sunlight exposure would reduce the analgesic usage of postoperative patients. The study used 89 patients, half of them under dim conditions and the other half at bright exposure of sunlight. The study has as result that bright side patients used 22% less analgesic and had 21% less analgesic medication cost than dim side patients [WDW+05]. This study can prove that natural light, at least under this study's specifications, is a concern to have during the architecture phase of hospitals and healing healthcare institutions.

2.3.8 Natural light vs Artificial light

Natural light is free and always available on exterior during daytime, but inside buildings it depends on the building's architecture and orientation. Artificial light on the other hand can be available on interiors, but has an economic cost.

Natural light has an inherent cycle that promotes the circadian rhythm and therefore alertness and energy during daytime and sleepiness during night time. However, artificial light isn't designed to turn off at night, exactly the opposite, is designed to stay on until trying to fall asleep, and in some cases even while we are sleeping. A study was performed to discover how much time light can delay the melatonin levels even after the lights are shut down, and concluded that there was a 90 minute delay after all the lights are turned off [GCS+10]. This means that if immediately before going to sleep there is exposure to: light of the television to watch a novel, lamps that are normally turned on for home orientation, a laptop for a last update of the news and then at bed a smartphone or tablet to check e–mails or social networks; then it is struggling to fall asleep because the SCN thinks that it is day already and the melatonin levels are the same as daytime [SPSH06].

There are different types of artificial lights. Nowadays, Light–Emitting Diodes (LED) are becoming widely used and in growth [Bea14], which produces a light with high amounts of short wavelengths. A possible solution would be to use a full–spectrum fluorescent light that is more similar to natural light, however there are still no concrete proofs that these fluorescent lights would be better, and at an economic point of view, these lights wouldn't be a good replacement since they are about 6 times more expensive and less energy–efficient, so it would cause a rise of the power bill to maintain the same levels of brightness [ET02]. One thing to keep in mind is that none of this artificial lights are stock equipped to change throughout the day, they are static while sunlight changes its intensity and color from dawn to dusk.

2.3.9 Light in Buildings

As shown previously, light is a major concern in healthcare facilities. Light can influence mood and perception of people as several studies suggested [BHH03]. Workers tend to choose spots to work near windows with natural light and showed higher satisfaction than when working away from windows, because daylight and a view tend to be desirable. Light conditions can affect productivity, happiness, and job–satisfaction for performing visual tasks. Daylight's spectrum of wavelengths is normally more complete than artificial light, providing better color rendering, but also can cause glare and distraction [BHH03]. A reduction of stress and healthcare demands from workers with windows and natural light exposure is also reported [BHH03]. However, this area still needs further investigation.

2.3.10 Habits of our society

While light exposure at night time affects our sleep and living rhythms, as well as our mood and health, our society is opening the door for this event. Modern society is full of light, even during night time, from reading using tablets, to cellphone usage in bed. 95% of the population of America said that they use electronic equipment within one hour before they go to bed, at least a few nights a week [Kre13]. It was shown that the exposure to light of 1000 Lux - similar to a cloudy daylight [Sch10] for 1 hour is enough for bringing the human melatonin levels from night time to day time [SPSH06]. This causes a confused SCN and a wrong circadian cycle that causes sleep deprivation with serious problems associated with it, namely, cardiovascular disease and diabetes risk factors, depression, automobile and workplace accidents, learning and memory problems, and an overall increase in mortality [KF09].

Technology is evolving more and more, and with it its usage is increasing as well. People now use technological devices for almost everything and at any time. To make the situation even worse, the screens also evolved from Cathode Ray Tube (CRT) to LEDs. This evolution, in terms of circadian rhythm, isn't healthy since CRT wasn't as harmful as LED because CRT uses Cold Cathode Fluorescent Lamp (CCFL) as back–light, which emits a wide spectrum of wavelengths. However, nowadays back–lighted LED screens emit twice as much the shorter wavelengths (bluish) than CRT or any other non–LED CCFL backlighted screen. This results on an easier and faster deregulation of the Circadian Rhythm like several studies have exposed [Giu12].

A similar process is happening in public illumination where sodium vapor light bulbs are being changed to more Energy–efficient LED lights. This sodium vapor bulbs are yellowed lights where the LED are bluish lights that have more repercussions to circadian rhythm.

Since the blue color reception in our retina is the main problem in melatonin suppression, a way to overcome this problem is to block the respective wavelengths to reach our eyes. Some programs like *f.lux* [f.l13] change the emission of screen colors from computers and mobiles throughout the day without any user interaction, only with the current time information at the specified time zone. Nevertheless, even at night we are surrounded by other light emissions (like chandeliers or even ceiling bulbs) that are not modulated and reach our eyes, making this software less effective or even ineffective. Other solutions go toward amber–lensed goggles that are orange and filters the blue–wavelength lights, independently of the source of the light. There are even some proper amber–lenses to use on top of normal glasses. A study shows that orange–lens decreases 94% of melatonin suppression where grey–lens decreases only 54% [SPSH06]

Chapter 3

The Philips illumination systems and project technologies

In this chapter the current state of knowledge in several subjects is described, including similar projects and a technical overview.

Philips Hue system, related projects and relevant technologies in the context are also included.

3.1 Philips illumination systems and related projects

Illumination systems allow the control of several colors, intensities, and even variations through computing systems. It can be built interconnecting several pieces of hardware like bulbs with several characteristics, controllers like dimmers and others, electronics, digital interfaces, computer systems and computer applications of many features and architectures. The illumination branch of Philips created recently an illumination kit ready for installation and use, allowing multicolor bulbs and several types of control, known as Philips Hue. Philips has also presented solutions for Hospital and School illumination, briefly presented below.

3.1.1 Philips Hue

Philips Hue is a product composed by one or more LED RGB light bulbs connected through wireless to a bridge that is connected to the internet and smartphone or tablet. Philips hue has available three different types of light bulbs, BR30, A19 and GU10 [Hue14]. All of them are able to produce 16 million colors and all shades of white. The differences between them is illuminance and beam angle, where BR30 have higher illuminance and emitted light is slightly narrow, A19 have a little lower illuminance than BR10 but the light emitted is wider, and GU10 is the one with lowest illuminance and angle.

Philips Hue allows users to download several mobile apps that let users to directly manipulate the light bulbs through a connection to the wireless bridge. These mobile apps have still a connection with IFTTT (details on IFTTT are present on section 3.2.2.8) service that allows changes to happen on the light bulbs if events happen in the device, e.g. the reception of a weather notification or an e-mail. IFTTT connection with the Philips Hue, allows not only connections to mobiles, but also to other services like e–mail or Facebook accounts [IFT14].

The Bridge and light bulbs work with a ZigBee model, i.e. a wireless protocol that uses low–power energy and allows a wide range of devices that aims to device-to-device communication on a mesh–network [Zig14]

IFTTT supports mobile apps for Android, iPhone and iPad devices. This way, it is possible to be noticed directly to the devices using push notifications. Those mobile apps allows also other triggering events, like synchronization of contact list of Android contacts, to open drive, or send e–mail to notify missed calls.

3.1.2 Philips Hue API

Philips Hue light bulbs are connected to one bridge, this bridge is responsible for command actions to the light bulbs. The bridge also provides an Application Program Interfaces (API, detailed on Web API, section 3.2.2.4) for developers to create their own application with interaction to the Philips Hue system.

Philips Hue API provides several types of classes, like lights, groups and scenes. Lights represent the light bulbs and can be used for interaction with a specific light bulb. Groups are a set of light bulbs and can be used for interacting with more than one light at once. Scenes are a group of light bulbs linked with lighting status. Can be used for example to change a light Group to previously recorded scenes.

After configuration of the bridge the creation of users is possible by a POST Hypertext Transfer Protocol (HTTP) Request containing “devicetype” and “username” information to “/api” URL. After successful creation of one user, is possible to request several services like those described on table 3.1:

Table 3.1: Philips Hue API Methods

Description	**Request**	**Response**
Get all light status	– GET – /api/<username>/lights	All light bulbs current status information
Set light status	– PUT – /api/<username>/lights/<id>/state – on (Boolean) – bri (uint8, brightness from 1 to 254) – hue (uint16, hue color value from 0 to 65535)	Success or error message
Get light group	– GET – /api/<username>/groups	All groups, with information about which light bulb belongs to each group and the group current status
Create group	– POST – /api/<username>/groups – lights (lights Ids) – name (String)	Success or error message
Set group attributes	– PUT – /api/<username>/groups/<id> – on, bri, hue, sceneID	Success or error message
Create scene	– PUT – /api/<username>/scenes/<id> – lights (lights Ids) – name (String)	Success or error message

Philips Hue Bridge provides three different methods to set light color:

– hue and saturation, hue is an integer from 0 to 65535 and saturation another integer but from 0 to 254;

– xy, i.e. list of 2 numbers, the x and the y, started and finished with rectangular brackets "[" and "]" and separated by a comma. x and y are float numbers up to 4 decimal figures that represent the x and y coordinates of CIE color space (Figure 3.1); e.g. "xy": [0.675,0.322] for red color;

– ct, represent the "reciprocal mega kelvin" aka "mirek" color temperature, i.e. a representation of the desired color temperature, integer from 500 (represent 2000K) to 153(6500K).

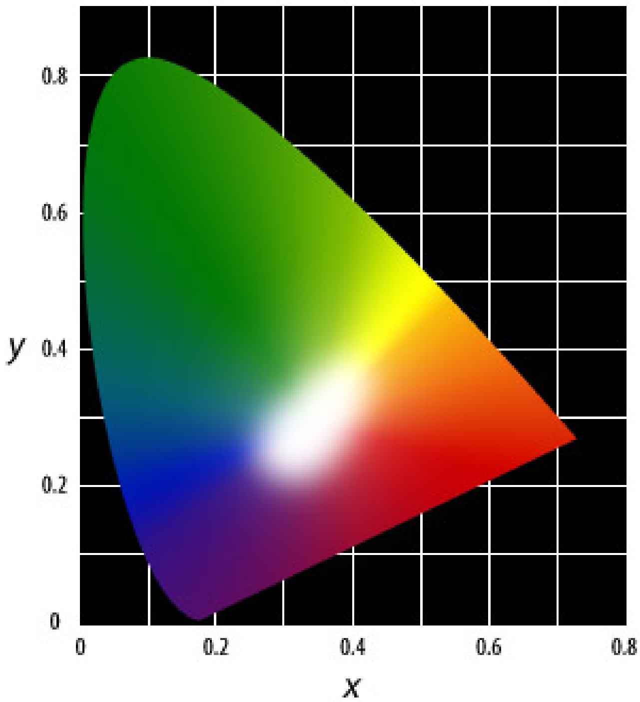

Figure 3.1: CIE color model with x and y coordinates. Image taken from [Sys00]

3.1.3 Philips HealWell

Philips HealWell [Phi11b] is a lighting system targeted for hospitals. This solution is composed by ambient colored light, dynamic light with varying light levels according to the time of day, reading and orientation light. Patients have a controller to manipulate colored lights in order to set the ambience with their preferences. Staff can set the dynamic light instantly brighter for examination or emergencies. HealWell uses dynamic lighting to promote patient's comfort, satisfaction, mood and quality of sleep as well as staff performance. Using light that changes throughout the day in order to simulate the rhythm of sunlight as well as promoting pleasant ambience for patients, HealWell solution is able to increase sleep time as well as decrease time to fall asleep.

3.1.4 Philips SchoolVision

Philips SchoolVision [Phi11a] simulates the patterns of daylight inside classrooms. SchoolVision has as objective to promote students' focus and learning capabilities. This solution uses different illuminances and color temperatures for four different settings: Energy, Focus, Calm and Standard. Each setting has a different purpose. The energy setting is used to activate the students in the beginning of the day and after lunch, while the focus setting is used for challenging tasks that require more concentration. The calm setting promotes relaxation at the end of the day as well as calm down hyperactive class. The standard setting for typical class activities like reading and writing. The teacher is the one responsible for changing the settings accordingly to each situation.

3.1.5 Halcyon-Lighting

Halcyon-Lightint [Hal15] is an integrated lighting system for both personal and professional use. Halcyon's system is composed by a set of light bulbs and a server.

The system performs automatic updates to promote the circadian rhythm and allows users to change the lights' current status using a web browser.

3.2 Application development technologies for personal illumination control

In this section a technological overview of several components that can be used in the development of a illumination solution, as well as a resume of the characteristics of the components, is presented.

3.2.1 Mobile Devices

A mobile device is a small technological device. It can be also known as handheld computer because normally it can be held and manipulated easily with the hand. smartphones, Tablet PCs, PDAs and Ultra–Mobile PCs are all different kind of Mobile devices. All these devices have normally in common several hardware like touch–screen monitor, speakers, microphone and internet connectivity through wireless LAN or mobile data from the operators.

3.2.1.1 Android

Android is an Operating System (OS) targeted for mobile devices. This OS was developed by Google and Open Handset Alliance in 2007, Android is based on Linux operating System and uses Open source code mostly written in C/C++ and Java [Ope14].

Android applications can be developed using an Integrated Development Environment (IDE), i.e. a set of programming tools composed by a code editor, compiler, debugger and Graphical User Interface (GUI) [PCM13]. Eclipse or NetBeans are some examples of free IDEs. Android provides several ways of developing. Android Studio is an IDE released in December 2014 by Google [And14]. Android can be developed using other IDEs, like Eclipse. Google provides a Software Development Kit that separates into packets several blocks of software needed to start developing on other environments.

It is possible to develop Android Apps that connects to the internet, using normal HTTP requests or socket based connections

Usually Android operations run on the front stage, i.e. on the User Interface (UI) thread, so that the user can see what is happening. However, for long time running operations, this practice can lead to unstable UI as well as frustrating users. Because of that, the usage of the UI thread for long time running operations, isn't neither advised neither a good programming practice. Background Services are Android operations that runs behind the UI and can be set to run while the application is not visible and after the application is closed. Android devices provides the IntentService class that allows the creation of such services. If the background service needs to communicate some event to the UI thread, it can be done using messages. The UI should be ready to ear and react to the specific message from the background service.

Android devices also provides their own databases in SQLite. SQLite is a SQL database engine with the particularity that it is an embedded database that provide only local data storage for individual applications and devices, without the need to setup or administrate a database manager. However SQLite doesn't provide shared data or concurrency access [Gmb14, Goo15].

Android provides several other APIs and support for easy developing in all kinds of devices, from low level to high level Tablet PC and smartphones. Accordingly to StatCounter Android Operating System is the most used Operating System for Mobile devices worldwide, with 59% of the market worldwide and 62% in Europe at the end of 2014.

3.2.1.2 Open Handset Alliance

Composed by 84 technology and mobile companies, Open Handset Alliance is a group of companies with the shared goal to provide a better mobile experience and easier development processes [All07]

3.2.2 Software Architecture

There isn't a broadly agreed definition of software architecture, however, one that is worth knowing is that software architecture is the adaptation of software engineering practices and methods in the current needs based on the trends [JT10]. Software architecture is a way to regulate and restrict all the components, interfaces and communications that will compose the system in a way that all the requirements are fulfilled optimally. It has as objective to help the design of the software structure, explain the system to others and guide the development of the software.

3.2.2.1 Server

A server is a software application that provides some sort of service to clients in a client–server architecture. Normally they accept requests from client applications and answers back to them. Servers are used for connectivity and distribution issues and they can run on both dedicated computers or not, depending of the type of service that is provided and his critical value. There are several types of servers with different goals, e.g. Mail servers that provides communication between clients through emails, File servers that provides remote access of files to the clients and Web servers that provides World Wide Web's HTTP connections.

There are multiple programming languages to develop a Web Server, the most common is PHP [W3T15], which is well known in the web programming community. PHP is, besides widely used worldwide, normally preferred for learning web programming. However, it has some drawbacks like security [Cho08, McA14]. PHP is very easy and cheap to host mainly through LAMP (Linux + Apache + MySQL + PHP) shared servers. For developing a web page using PHP, it is required not only PHP programming, but normally also SQL for databases as well as HyperText Markup Language (HTML), CSS and some JavaScript.

3.2.2.2 Two–tier architecture

Two–tier architecture is a client–server model where the Server can offer the same services to several possible clients. The clients are the ones that ask for any kind of service or resource from the server. Web applications are generally two–tier applications where the server provides the data and the client applications provides an interface to access data from the server through internet [Ree00]

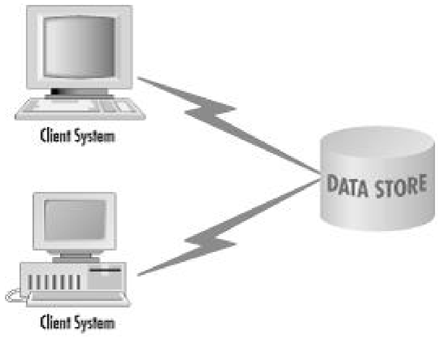

Figure 3.2: Sample of a typical two–tier architecture. Image taken from [Ree00]

Two–tier architecture is mainly used for client–server communication where it doesn't require many data interpretation, manipulation or processing [Ree00].

3.2.2.3 Three–tier architecture

Three–tier architecture is the simplest kind of architecture for N–Tier architectures. In this architecture the system is composed by a presentation tier, logic tier and the database tier. Presentation tier is where the UI is. The logic tier is where all the "business rules" are defined as well as data from database is represented in the form of objects. The database tier is where all the requests to the database are processed. This architecture allows not only to physically separate the three tiers, but also to develop them separately. The added tier allows the client applications to see the updated data, eliminating the risks of dirty writes. Scalability with this kind of architecture is better, since it is possible to escalate the tiers independently with less code change [Ree00].

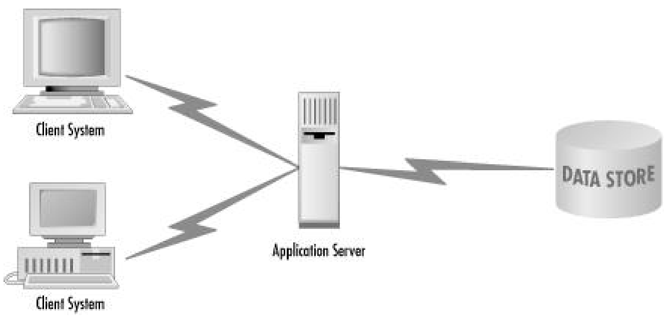

Figure 3.3: Sample of a typical three–tier architecture. Image taken from [Ree00]

The drawbacks of this kind of architecture are mainly the difficulty to develop and maintain such a system. It requires more skilled software engineers that are conformable with N–tier programming. Also, it requires more maintenance since there are more components in the system [Ree00].

3.2.2.4 Web API

Several servers provides Web Application Program Interfaces (Web APIs), i.e., a service that offers a software-to-software interface for client applications to access Web--based software application through HTTP requests [Rou07]. These HTTP requests are normally responded in JavaScript Object Notation (JSON) or Extensive Markup Language (XML) formats. This way it is possible to establish a communication tunnel from several applications to communicate through. As an example, Amazon's API offers a way allowing other applications search and buy products from Amazon [Roo08].

3.2.2.5 Node.Js

Node.Js is a framework that is getting more and more popular. It uses JavaScript language and is known by his event–driven architecture and non–blocking input/output model. This framework is built on top of V8 JavaScript Engine that provides a great performance at low CPU cost, plus is an open source package written in C++ from Google and used in Google Chrome Browser [Tea15]. The Node.Js version 0.0.1 was released in May of 2009 [git09].

Node.Js allows not only the development of the backend replacing the standard PHP, but also allows the development of frontend and database through JavaScript using for example Angular.js and MongoDB. On the dark side, Node.Js due to his relatively new concept of event–driven and asynchronous architecture, is harder to start learning because it takes more time to fully understand it and getting used to.

Node.Js uses several packages or libraries for different requirements from the developer. If, for example, an XML or JSON converter is needed, it can be easily obtained by the Node Package Manager (NPM). NPM is an online repository for open source Node.Js projects and a command–line interface that communicates and installs packages from the online repository [Nod11]

3.2.2.6 Angular.Js

Angular.Js is a framework used for building dynamic web pages using JavaScript on a Model-View-Control (MVC) architecture. Angular.Js allows data binding, forms and validations, DOM event handling, among others, to interact with HTML making the webpage dynamic instead of a static document that is HTML [Ang15b].

Angular.Js allows Two-Way Data Binding, i.e. update the view accordingly to the data and update the data accordingly to UI interactions, like shown in Figure 3.4.

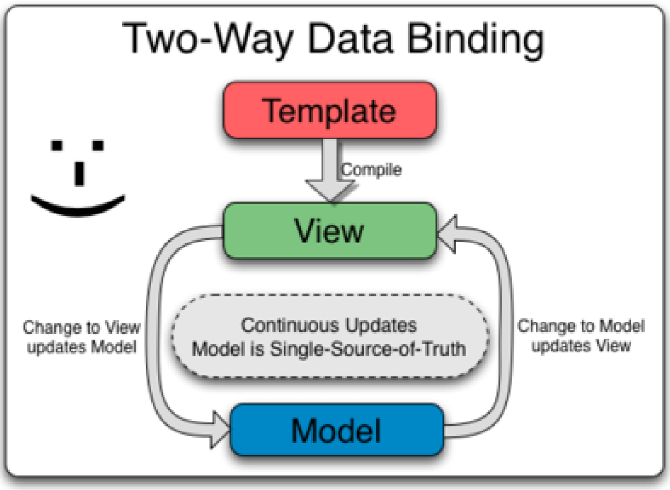

Figure 3.4: Two-Way data binding. Image taken from [Ang15a]

3.2.2.7 MongoDB

MongoDB is a Not Only SQL (NoSQL) open–source document database. Written in C++, MongoDB uses JSON–style document–oriented storage and allows dynamic queries in JavaScript [Kov15]. Accordingly to MongoDB Webpage, MongoDB is the leading NoSQL database, on top of Google searches as well as LinkedIn's job skills [Mon13]. Node.Js have an official MongoDB driver that allows a native asynchronous Node.js interface to MongoDB which uses only JavaScript [Mon14]

NoSQL was developed in the early 2000s in order to provide higher scalability, replication and unstructured data storage that SQL Databases don't support For example NoSQL allows data storage in XML or JSON formats, while SQL requires table and column format [Mon15]

3.2.2.8 IFTTT

IFTTT means If-This-Then-That (IFTTT) and is a service that provides communication from known services (IFTTT calls them channels) like Facebook, Gmail, Feedly, Weather, etc. to other channels [IFT15]. IFTTT is composed by Channels, Triggers, Actions, Ingredients and Recipes. Channels are the services that IFTTT can work with, Triggers are the events that need to happen for the communication to start and represent the "This" part on "If-This-Then-That" Actions are the "That" part, i.e. the activity that should take place after the initial trigger. The ingredients are the data inside the Triggers, for example, Email Triggers can be the subject, sender, body or attachments. Recipes are the Trigger, Action and Ingredients all combined. As an example of IFTTT usage, the recipe: If Weather Channel says it is going to rain tomorrow, then notify the user by e–mail.

Chapter 4

Solution description and user stories

In this chapter a solution for building a colorized illumination system is proposed and described. Some user stories to which it should respond are also included. The solution is composed by the requirements, used technologies, holistic point of view, and a brief explanation of each module that makes part of the solution.

4.1 Requirements, assigned technologies and solution's holistic view

To meet all the objectives previously stated in chapter 1, the project should fulfill the following requirements:

Table 4.1: Project Requirements

Importance	**Requirement**
Must	Availability: All time accessible
Must	Maintainability: System must be able to keep its state updated
Must	Non-Blocking & User-friendly UI
Must	Fewer communication, data and connections as possible
Must	Reliability on system's usage
Should	Portability: Everywhere accessible
Should	Security: Access control to the system

The project has some constraints:

1. Users need to have Philips Hue Bridge and Philips Hue Lights installed, as the chosen technology for illumination;
2. Hue Bridge can only be accessed on the local network;

3. User should have the SmartCompanion launcher on Android smartphone to take advantage of all the features;

The constraint 2 means that Philips Hue's development team only published the local API, the remote API is still under development and its access restricted [Hue15] (login is required). To access the remote API, a request need to be filled. This request was submitted on 16th November 2014, and we are still waiting for an answer from Philips Hue's development team.

Therefore, only two possible solutions can be found: 1) Use a static IP Address and open a port at home network. This way the bridge can be accessed from outside of the local network; 2) The server needs to communicate with the Hue Bridge locally.

The first option requires some technical knowledge and opportunity to open ports on the network. This option was automatically discarded, since it wasn't an option to open ports on Fraunhofer's facilities.

The second option prevents the requirement Portability to be fulfilled, since all the system must be on local network, and therefore, the Security requirement isn't a concern anymore, because all the requests are coming from inside the local network. However, if this option wasn't the adopted one, an access control layer should be implemented, to restrict the system's access to only authorized users.

On table 4.2 some keywords used in the problem's scope are explained.

Table 4.2: Concepts or Terminology

Concept	Description
Group	Set of one or more lights
Scene	Specifies a set of lighting actions (color, saturation, brightness and blink) for several Lights or ***Groups***
Trigger	Predefined event originated by a user or automatically that will produce a chain of actions by the system
Rule	Relationship between a ***Trigger*** and ***Scene***, can be active (subscribed) or inactive (unsubscribed). Eg: "When ***Trigger*** happens, if ***Rule***.Active activate ***Scene***

The system is composed by an Android application, a web application, a web server and the Philips Hue package that includes the light bulbs, sockets and the bridge, as shown in Figure 4.1.

The web server is developed with Node.Js because, as mentioned previously, it is a technology that is getting increasingly popular and has an event-driven architecture that allows communication in a non-blocking user interface. It provides as well the usage of different packages from NPM like node-schedule and socket.io. These libraries are used in updating the lights accordingly to the time of the day and to communicate with client applications. The server is in charge of all communications to the bridge, which is responsible to manage the light actions.

The Android application provides a user interface to subscribe or unsubscribe ***Triggers*** that are activated when certain events happen, for example, an SMS or phone call reception or fall detection, and to apply predefined ***Rules***.

The web application is developed on AngularJS since it allows two-way data binding and MVC architecture with the same programming language as the Server, JavaScript. It will provide a proper communication and non-blocking UI. The web application allows the user to subscribe or unsubscribe ***Triggers***, just like the Android App, in addition to manage more complex user settings, e.g. ***Groups***, ***Scenes*** and ***Rules*** accordingly to each ***Trigger***.

All the user settings will be communicated to the web server and stored on a MongoDB database. MongoDB was chosen not only because Node.Js have an official MongoDB driver, but also because it uses JavaScript, allows dynamic queries and unstructured storage with JSON.

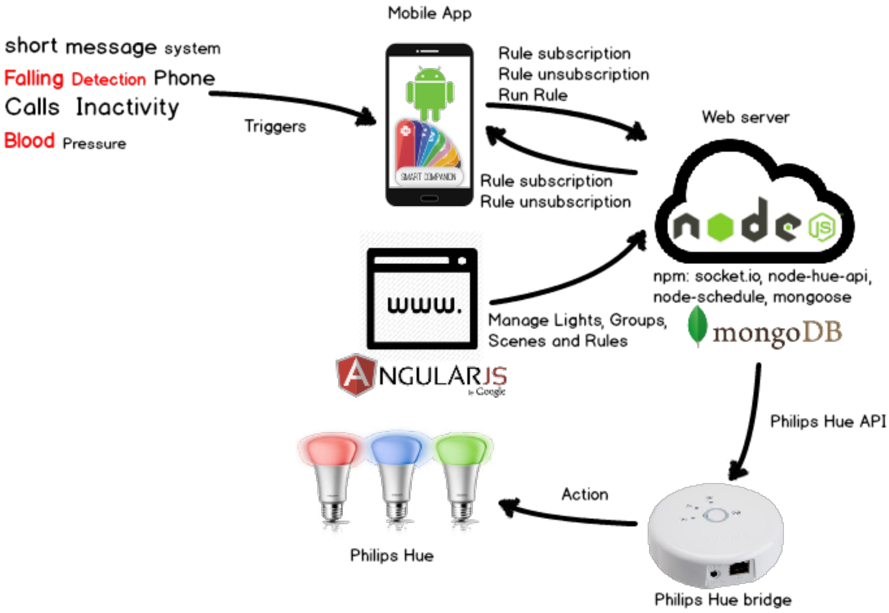

Figure 4.1: Holistic view of the solution.

4.2 Module description and assignment

As referred in section 1.1, this work is integrated with the SmartCompanion project that is targeted for elderly people and their caregivers. Therefore, this project needs to fit in the SmartCompanion targets' requirements and constraints.

As a result, major concerns while planning and developing this project are the little knowledge that elderly people have around technology, uncommon and limited interaction with smartphones and poor vision.

This project is composed by two UI Modules, the Web Application and the Mobile Application.

The Mobile Application is aimed for the elderly to use from the SmartCompanion launcher. It will allow the elderly to call SOS, turn on/off user-defined rules and call rules' scenes manually or automatically (by triggering events).

One simple use case example of an elder person using the Mobile Application is in the case of having a migraine and activate, through the Android App, the lighting scene pre-defined to this situation. The same should happen for other users current anomalies like low/high pulse rate or pain.

The Web Application is intended to be used by the caregiver, who is more knowledgeable and more familiarized with technology. The Web Application will allow the caregiver to set current light status and manage all the user-settings for the illumination system.

4.3 User stories

In this section all the user stories for different users and platforms are detailed.

User stories are a set of sentences with the objective to define and explain the system requirements and features that are being developed.

Table 4.3 shows the main users and their characterization.

Table 4.3: Users

Name	**Description**
Elderly	– Low mobility – Hearing impaired – Falling concerned – Low technology knowledge
Caregiver	– Concern with elderly's health and wellbeing – High technology knowledge

Table 4.4 lists all the user stories required by the project owner.

Table 4.4: User stories

Platform	**As a/an**	**I want to...**	**So that...**	**US**
Web App - Home	Caregiver	trigger an SOS alert	I can visually notify an emergency	US01
Web App - Lights	Caregiver	see all lights' current status	I know all the lights and their current status	US02
Web App - Lights	Caregiver	change a specific light's name	lights have a personalized name	US03
Web App - Lights	Caregiver	turn on/off a specific light	I can manipulate it	US04
Web App - Lights	Caregiver	change light's current hue	I can get visual perception	US05
Web App - Lights	Caregiver	change light's current color temperature	I can get visual perception	US06
Web App - Lights	Caregiver	change light's current saturation	I can get visual perception	US07

Web App - Lights	Caregiver	change light's current brightness	I can get visual perception	US08
Web App - Lights	Caregiver	change light's blinking status	I can get visual perception	US09
Web App - Groups	Caregiver	see all ***Groups***	I know all the ***Groups*** already created	US10
Web App - Groups	Caregiver	create a new ***Group***	I can create future ***Scenes*** that will operate this ***Group***	US11
Web App - Groups	Caregiver	remove a specific ***Group***	I can delete a ***Group*** that is no longer needed	US12
Web App - Groups	Caregiver	change the name of a specific ***Group***	I can keep the ***Group*** names updated	US13
Web App - Groups	Caregiver	change what lights belongs to a specific ***Group***	I can add/remove lights from a ***Group***	US14
Web App - Scenes	Caregiver	see all ***Scenes***	I know all the ***Scenes*** already created	US15
Web App - Scenes	Caregiver	create a new ***Scene*** with specific lights or ***Groups***	I can save ***Scenes*** for playing in the future	US16
Web App - Scenes	Caregiver	remove a specific ***Scene***	I can delete a ***Scene*** that is no longer needed	US17
Web App - Scenes	Caregiver	play a specific ***Scene***	I can easily replay a ***Scene*** previously created	US18
Web App - Rules	Caregiver	see all ***Rules***	I know all the ***Rules*** already created	US19
Web App - Rules	Caregiver	turn on/off a specific ***Rule***	I can enable/disable ***Rules***	US20
Web App - Rules	Caregiver	create a new ***Rule***	I can specify which ***Scene*** to play for each ***Trigger***	US21
Web App - Rules	Caregiver	remove a specific ***Rule***	I can delete a ***Rule*** that is no longer needed	US22
Web App - Rules	Caregiver	enable/disable circadian rhythm automatic updates	I enable/disable circadian rhythm updates accordingly to mine or elderly's preference	US23
Mobile App	Elderly	trigger an SOS alert	I can visually notify an emergency	US24
Mobile App	Elderly	turn on/off a specific ***Rule***	I can enable/disable ***Rules***	US25

Mobile App	Elderly	play a ***Scene*** from a specific ***Rule***	I can easily replay a ***Rule*** previously defined in case of need or to watch what is the action from that specific ***Trigger***	US26
Mobile App	Elderly	be visually notified when an ***Trigger*** occurs	I have a visual update for notifications like SMS or phone call receptions and a proper environment for my health conditions like low/high blood pressure	US27

The user stories shown on table 4.4 allow to conclude that the system should:

- Provide easy manipulation and creation of ***Scenes***, ***Rules*** and ***Groups***;
- Automatically update lighting status accordingly to time, to promote circadian rhythm;
- Apply pre-programmed lighting configurations;
- Read external events and react, updating light status.

4.4 Usage scenarios

The solution developed has several purposes and therefore can be used in different scenarios.

There are two main purposes: Health related and personal notification assistance.

The principal scenario is to use the developed system in nursing homes, since it is a place that elderly people usually spend some of their time and is shared with caregivers (professionals from the nursing home). With this scenario, it is possible to: 1) Provide a good environment for a large group of elderly people, taking advantage of the lights to promote the circadian rhythm and health related conditions (Migraines, High/low blood pressure, Fall detection, etc.); 2) Have personalized notifications from the reception of phone calls or SMS (considering that each elderly have his personal light or a unique set of colors). For this scenario to work is necessary to install one Hue Bridge and multiple Hue light bulbs.

A second possible usage scenario is to use this system in a home where the elderly live with a caregiver. This system will allow to use the full range of features without any constraint (like the constraint present in the first scenario, that is the number of lights or colors available for the several seniors). In this environment it is possible to use all health related features personalized for the only elderly present with all the lights and colors to notify the elderly or the caregiver about external events. This scenario requires only one Hue Bridge and fewer lights than the first scenario,

A third possible scenario to use in the future, if an official remote API is provided by Philips Hue, is to install the system in two living places, where the elderly lives and where the caregiver (possibly the closest relative) lives. In this case all health related actions will be done at the elderly home, as well as personal notifications (SMS or phone call reception). Notifications about the falling or help requested from the elderly should be sent to the caregiver place.

Chapter 5

Architecture and Implementation

In this chapter the architecture and implementation of the system are detailed and explained. This chapter is composed by the physical architecture of all the system, Web server details, Database architecture and Web application details followed by the Mobile application architecture.

5.1 Physical Architecture

The diagram 5.1 shows the Physical Architecture for all components that compose the solution.

The Web application is physically located on the Server, however the Web browser from the user's computer loads it locally. The connection from the Web application to the Web server is established via HTTP requests and Web Sockets.

The Mobile application is present on the final user's smartphone that runs Android OS. As stated in 4.1, the smartphone should have the SmartCompanion Launcher installed. The communication between the Mobile application and the Web server is established entirely by Web Sockets.

The Server is composed by the Web application running on Apache, the Web server files that are running with Node.Js and the Database running with MondoDB. The Web server receives all the requests from the Web application and the Mobile application and sends them to the Hue Bridge, that will trigger actions to the lights. Also, the Web server can start the communication with the Hue Bridge by itself and store all necessary information on the Database.

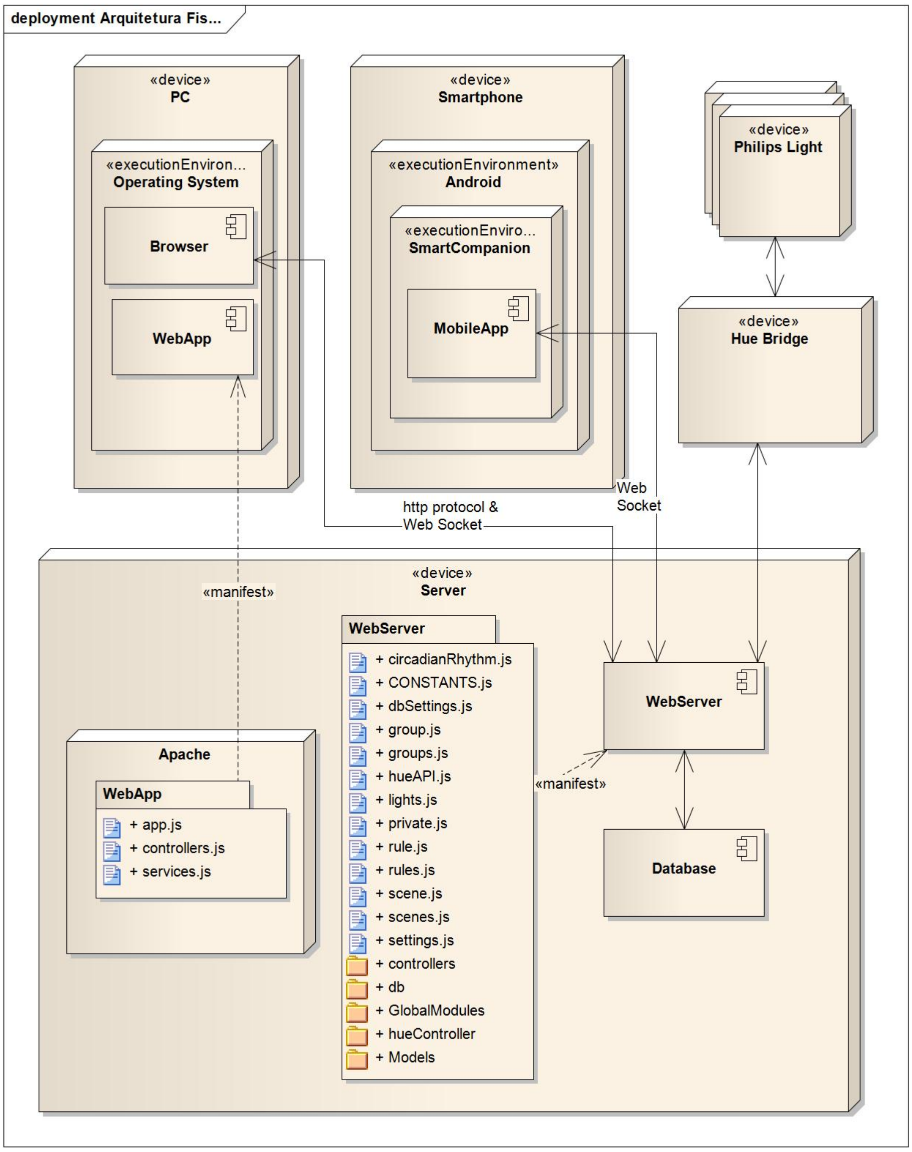

Figure 5.1: Physical Architecture of the solution

The solution follows an MVC system architecture, where the Model component is represented by the Hue Bridge and the Web server Database, the View by the Mobile application and the Web App, and the controller layer by the Web server Application.

5.2 Web Server

The Web server architecture is detailed in Figure 5.2, where we can see displayed in red the Database layer.

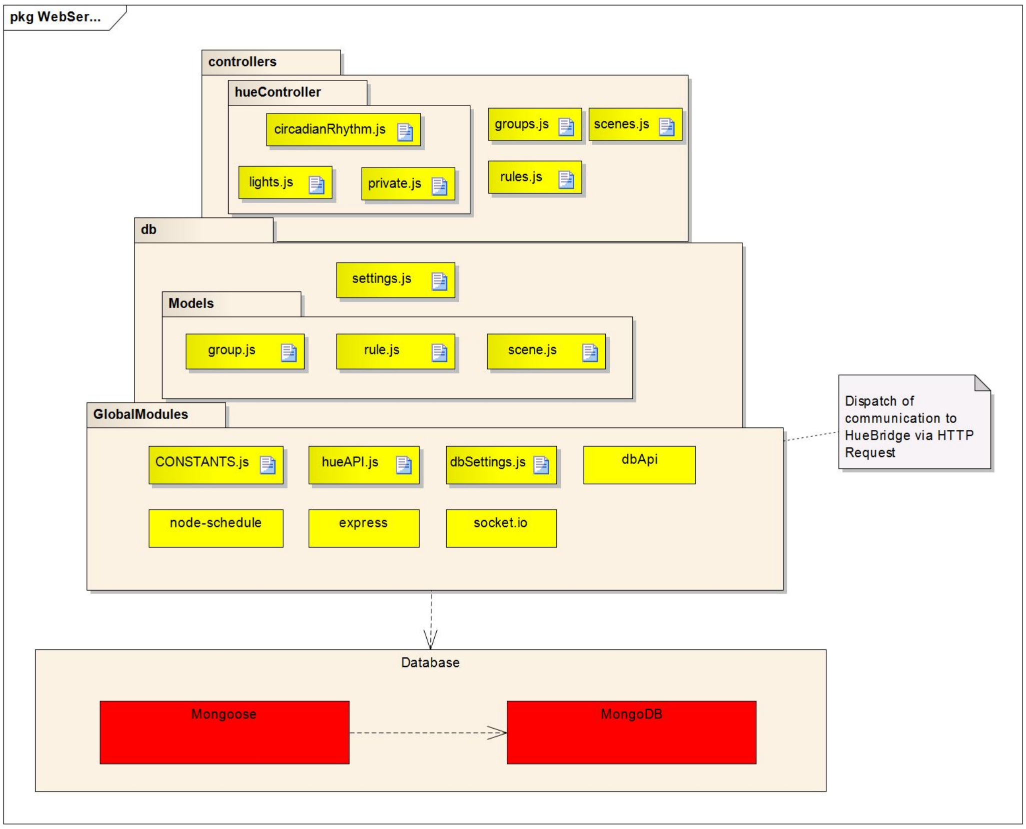

Figure 5.2: Web server Layered Architecture

MongoDB is used to store all data needed, using Mongoose which is an official MongoDB driver for Node.Js applications. On top of the Database layer are the *GlobalModules* layer. This means that all layers above the *GlobalModules* layer have access to this one. This layer have the files CONSTANTS.js, HueAPI.js and dbSettings.js, that implement some constant variables, the Philips Hue API and start up some Database dependencies, respectively. Other dependencies are also initiated here, like dbApi (present on db layer), node–schedule, express and socket.io.

The package node-schedule is used to schedule events during the day, providing automatic updates on the Hue Lights necessary to promote the Circadian Rhythm (see Listing 5.1, line 28).

The Express package is used to allow the Web server application to interact not only with Websocket connections, but also with HTTP requests. This feature was used firstly for testing during development phase, but secondly to allow an advanced user to use specific features like create or delete users from the Philips Hue Bridge and even simulate the press of a physical button of the Hue Bridge, for configuration purposes. For example, use http://[serveraddress]:8080/api/hue/private/press to simulate the press of a physical button on Philips Hue Bridge.

The Socket.io package is necessary to create a socket server for future communication with socket clients from Web Apps and Mobile Apps. To minimize the number of resources (TCP Connections) and to separate business logic rules from the models *Lights*, *Groups*, *Scenes* and *Rules*, custom namespaces were used for each model.

```
// ------------------------ On File db/models/rule.js: ------------------------
/*Function that runs when the server starts, creates triggers if not created yet and
    the same for CircadianRhythm Object*/
function populateDB(){
    /*Optional param checkTableExistance=true only needed on 1st call of createTrigger,
    is a flag to run table structure validation*/
    //Method: createTrigger(triggerName, [checkTableExistance])
  createTrigger("Fall Detection",true);//id == 0
  createTrigger("Phone Call");
  createTrigger("SMS");
  createTrigger("Help Request");
  createTrigger("Migraine"); // Blinking Red color
  createTrigger("Low Blood Pressure"); // Yellow color
  createTrigger("High Blood Pressure"); // Blue color
  createTrigger("Pain"); // Blue color
  createTrigger("Inactivity"); // Red color(increase excitement)

  //check if cr exists on DB, if not, creates one
  CircadianRythm.find(function(err,cr){
    if(cr.length == 0){
      var cr = new CircadianRythm();
      cr.active = true;
      cr.save();
    }
  })
}

// ------------- On File controllers/hueController/circadianRhythm.js: -------------
var schedule = global._modules.scheduler;
// increment of colorTemperature is 69,4 each 2 hours
var ct = [153,211,269,327,384,442,500];
//run every 2 hours from 8am to 8pm
var j = schedule.scheduleJob('0 8-20/2 * * *', function(){
  //update Color temperature
});
```

Listing 5.1: Partial code from Web server with side notes and explanations.

5.2.1 Database Architecture

The Database architecture is delineated around six data modules, satisfying all the persistent needs of the system.

The data modules that actually compose the Web server's Database are represented on figure 5.3.

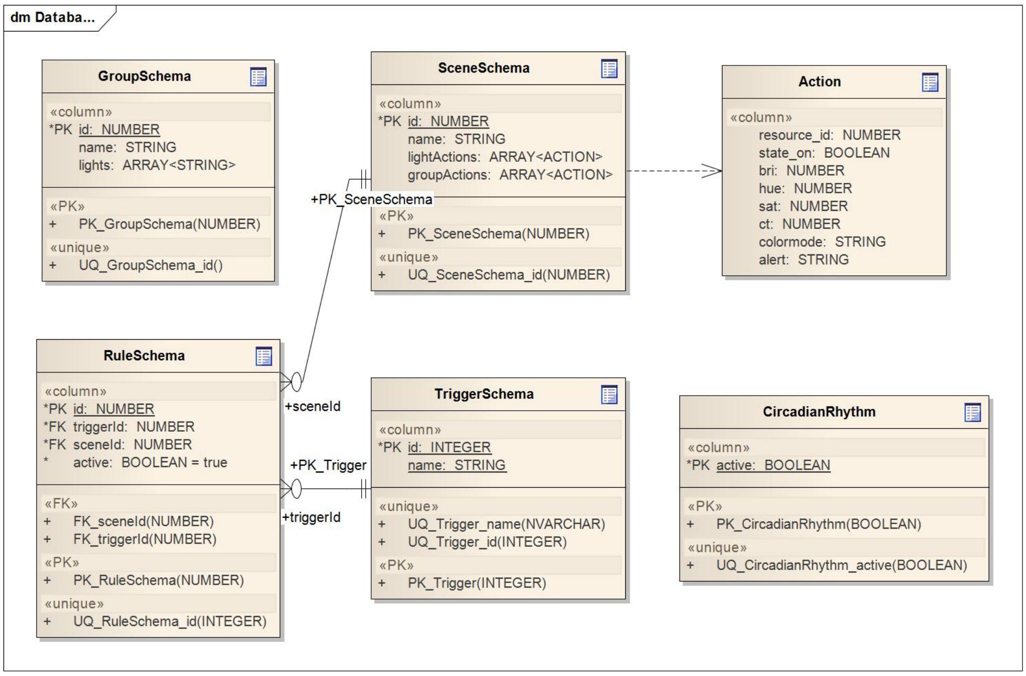

Figure 5.3: Database Architecture

On the GroupSchema data module, the attribute *lights* is an array of LightIds. These LightIds refer to light bulbs present on the Philips Hue System. An important note is that Light is the only model that is kept originally on the Philips Hue Bridge, since all physical actions need to be through real light bulbs present and detected by Philips Hue Bridge.

The Light Model is defined by the following JSON Object:

```
{
  "state": {
    "hue": uint16,
    "on": bool,
    "effect": string,
    "alert": string,
    "bri": uint8,
    "sat": uint8,
    "ct": uint16,
    "xy": list 2..2 of float 4,
    "reachable": bool,
    "colormode": string 2, 2
```

```
  },
  "type": string,
  "name": string 0, 32,
  "modelid": string 6, 6,
  "swversion": string 8, 8,
  "pointsymbol": object
}
```

The Actions data module is used to define the actions to be produced by the light bulbs. These Actions have all the light attributes that the Hue system allows to be changed. It also have a *resource_id* which identifies which light or group of lights will be affected.

In the SceneSchema data model, there are two variables for Actions data, the *lightActions* and the *groupActions*. This separation exists to prioritize light actions towards group actions, since they are more specific. In case of a scene that produces two actions to the same light, by *LightActions* and *GroupActions*, the light will suffer the action from *LightActions* but the action from *GroupActions* will only affect the other lights.

The TriggerSchema data model represents the ***Triggers***. These ones are statically inserted by the developer, as shown on Listing 5.1 line 7. They can be easily added using the function *createTrigger*.

The *CircadianRhythm* instance is an object kept on the database or immediately created internally representing the option to activate or deactivate circadian rhythm automatic updates (see Listing 5.1, line 17). It is a unique ***Trigger*** because the user shouldn't be allowed to change which ***Scene*** will produce, it depends only on the current time of the day.

On table 5.1 the Database requests are listed and described.

Table 5.1: Database Requests

Method	**Argument(s)**	**functionality**
getAllGroups		get all ***Groups***
getGroupById	groupId	get ***Group*** with id groupId
deleteGroup	id, socket	delete ***Group*** with id groupId, delete any ***Scene*** that have this ***Group*** and delete all ***Rules*** that run those ***Scenes*** deleted. Communicate the deletions to socket
saveGroup	group, socket	save ***Group*** and communicate to socket
editGroup	group, socket	set params of ***Group*** group and communicate to socket
getAllScenes		get all ***Scenes***
getSceneById	sceneId	get ***Scene*** with id sceneId
saveScene	scene, socket	save ***Scene*** and communicate to socket
deleteScene	sceneId, socket	delete ***Scene*** with id sceneId and delete any ***Rule*** that runs this ***Scene***. Communicate deletions to socket
getAllRules		get all ***Rules***
saveRule	rule, socket	save ***Rule*** and communicate to socket
deleteRule	ruleId, socket	delete ***Rule*** with id ruleId. Communicate deletion to socket
setRuleActive	ruleId, active, socket	update field active of ***Rule*** with id ruleId. Communicate update to socket
setCR	active, socket	update field active of CircadianRhythm Object. Communicate update to socket
isCrActivated		get CircadianRhythm active status
getSceneIdsByTriggerName	triggerName	get list of ids of scenes associated to a specific ***Trigger***

5.3 Web Application Architecture

The Web application allows the users to update lights' current status and manage all user-settings from the system.

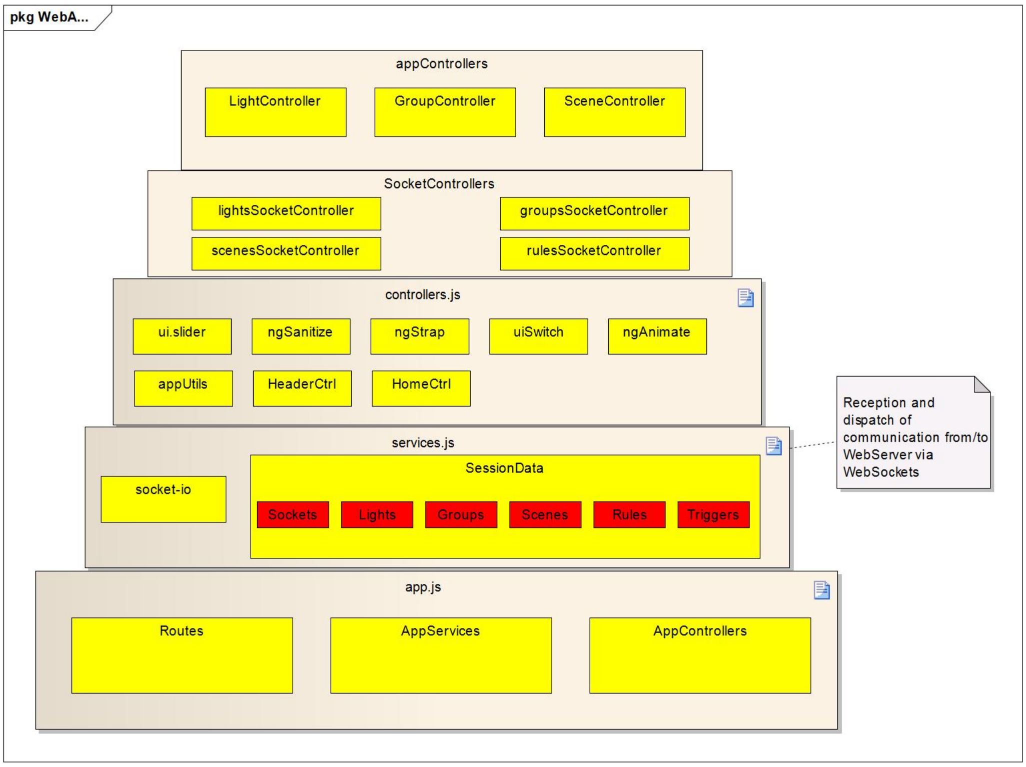

Figure 5.4: Web application Architecture

Figure 5.4 represent a layer software diagram for the Web App. At the bottom of the figure is the file *app.js*. This file starts the application, registers main dependencies, like ngRoute, AppServices and AppControllers.

The module ngRoute is a module necessary for navigation logic and defines which page uses which controller.

The module AppServices is defined on the file *services.js*, present in the layer above. This file initiates the socket.io dependency and is responsible not only for socket communication with Web server, but also to keep session data, during navigation, from the Web server, like the socket's connection, Lights, ***Groups***, ***Scenes***, ***Rules*** and ***Triggers***. This way, after gathering the data once, it is prevailed and updated in case of external or internal changes (see Listing in 5.2, line 19).

The layer *controllers.js* is responsible to initiate the module AppControllers, its dependencies, a module of utilities and some simple controllers like HeaderCtrl that is responsible for filling in the navigation tab with the current location, and HomeCtrl that provides two buttons, one to trigger an SOS alert, and the second to command the bridge to search for newly installed lights. This module's dependencies are UI dependencies, like *ui.slider* which is a module responsible to create sliders on UI; *ngSanitize* that provides the possibility to insert HTML code with AngularJs features on JavaScript Controllers; *ngStrap* which is a BootStrap version for AngularJs;

uiSwitch that provides some switch elements for the UI; and *ngAnimate* to program animations on UI. The *appUtils* module is a module for utility functions like correcting Hue values (explained in the section 5.3.1), rounding and converting from hexadecimal colors to HSV and the opposite.

In the 2nd top layer of the Figure 5.4 are the SocketControllers. These controllers are a link between the Socket in *services.js* and the several UI controllers like *LightController*, *GroupController* and *SceneController*. This layer was developed to allow several models like Lights, Groups or Scenes to communicate through one only controller per web page (#/lights, #/groups, #/scenes and #rules).

The top layer contains the final appControllers: *LightController*, *GroupController* and *SceneController*. The system allows adding multiple Lights, ***Groups*** or ***Scenes***. Each one of them needs UI to be managed. Therefore, the UI of the Web application increases accordingly to the number of Lights, ***Groups*** or ***Scenes*** present. Each one of them initiates a new controller and each controller will be shown on the UI and is responsible to manipulate and update its own parameters (see Listing 5.2, line 27).

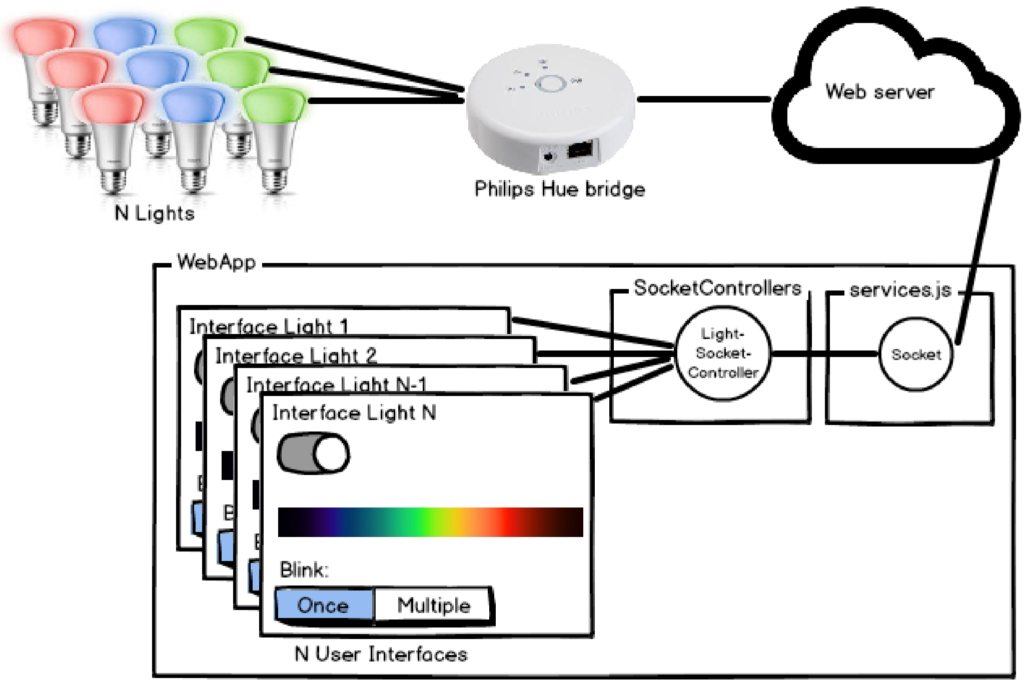

Figure 5.5: Connection between Lights and *LightControllers* on the Web App, similar with ***Groups*** or ***Scenes***

As shown in Figure 5.5, the Websocket connection to the Web server is opened on *services.js*. The *SocketControllers* layer then waits for Web server events like creation, deletion or modification of models, passing them to the responsible controller on the *appControllers* layer. On the other side, each controller on *appControllers* is waiting for user inputs, transmitting them to the Web server through the *SocketControllers*.

```
// ------------------------ On File GroupSocketController.js: ------------------------
/*function callback, will be called inside service.js (as param updateView)*/
function updateGroups(newgroups){
  $scope.groups = newgroups;
}
/*Function called every time that GroupSocketController is initiated (every navigation to #/Groups).
This is an example of a totally asynchronous, non-blocking interface. updateGroups (callback) will only be invoked when ready, but nothing is waiting for
that moment. Taking this way advantage of both AngularJS and socket.io event-driven architecture*/
service.askForGroups(updateGroups);

// ------------------------ On File services.js: // ------------------------
//var updateView is a callback from GroupSocketController, that will fill the UI
service.askForGroups = function(updateView){
    //callback that will run when socket answers
  var cb = function(ngroups){
      //function that parses ngroups received and call updateView with those groups
    recieveGroups(ngroups,updateView);
  }
  //only asks to the server once (the first time)
  if(groups.length < 1)
        groupSocket.emit('getGroups', cb); //ask for info
    else
      updateView(groups);
}

// ------------------------ On File lightController.js: // ------------------------
/*subscribe on socket (with namespace lights) for events that changed
light with id lightId, on those events call the function $scope.updateLightBri*/
service.uniqueOn(service.getLightsSocket(), 'updateLightBri', lightId, $scope.updateLightBri);

// ------------------------ On File lights.html: // ------------------------
//File template for #/lights
/*A new LightController is created for each light present on LightSocketController*/
<div class="light" ng-repeat="light in lights" ng-controller="LightController">
    ...
</div>
```

Listing 5.2: Partial code from Web application with side notes and explanations.

5.3.1 Hue Values Converter

The correction of hue values was done on *appUtils* to solve a problem found while testing the HSL color picker. Philips Hue light bulbs produce a very accurate range of color temperatures, from cool white bluish colors to warm orange colors. However, to produce such an accurate range of color temperatures, the Hue light bulbs are composed not by RGB leds but with 5 yellow, 2 blue and 4 red-orange leds as shown on Figure 5.6. This led composition compromises the normal red/green/blue color.

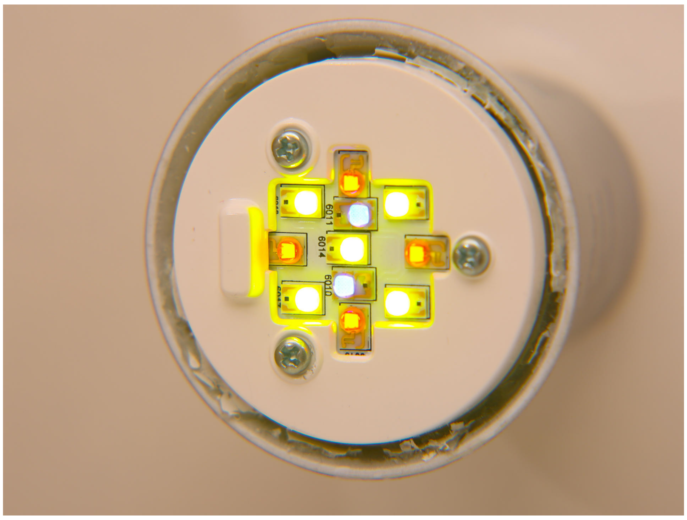

Figure 5.6: Inside Hue Light bulb. Image taken from [Cri14]

Due to this atypical led composition, the Hue light bulb produces, for example a tennis-green instead of green and a sunset orange instead of yellow. This leads applications to produce incorrect colors when using the official hue values. This is the case of WinHue [Win15]: when yellow is requested, it uses the hue value 12750 and the result is an orangy color, visible in Figure 5.7. When using the Hue official application for Android devices, the same request produces a greenish result, probably because they use their own converter (see Figure 5.8). In Lightbow's webpage [Lig15], this problem is also explained and solved using a custom hue converter.

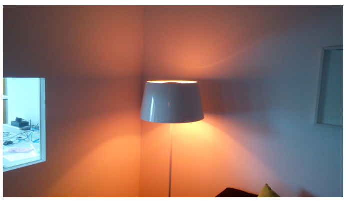

Figure 5.7: Yellow light with official hue value, using WinHue

Figure 5.8: Yellow light requested on official Hue application for Android

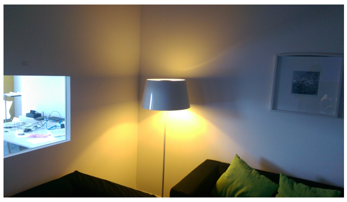

Figure 5.9: Yellow light using custom converter on Web App

Figure 5.10 shows the real hue value of each color on the X axis and on the Y axis is represented the hue value that should be sent to the Hue Bridge to produce that color. It is notorious that the higher difference from a straight line is around orange, yellow and green colors.

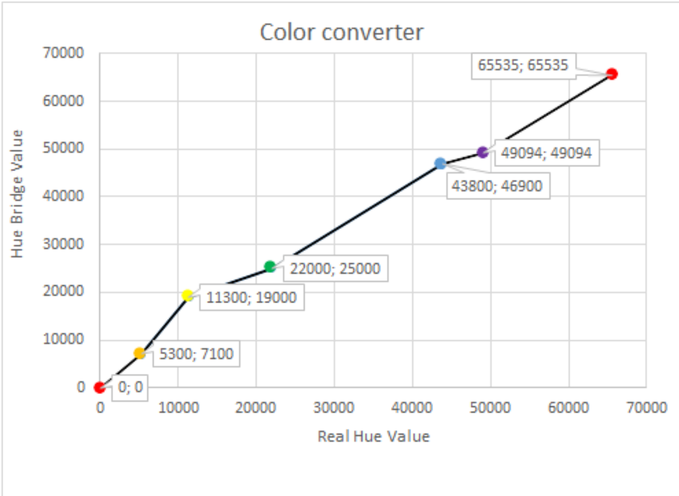

Figure 5.10: Graph of real hue values (X axis) and the ones that should be sent to the Hue Bridge (Y axis).

5.4 Mobile Application Architecture

The Mobile application is the component responsible for the interaction from the elderly to the system.

Figure 5.11 details the Mobile application architecture showing its main classes.

The main activity is the ALIAS activity. This activity extends a FragmentActivity, because it uses fragment elements of the SmartCompanion library. It requires socket connection for exchanging data with ***Rules*** and ***Scenes***.

This activity uses an adapter to list all ***Rules*** received from the Web server. The class RulesAdapter is used to create this adapter and extends BaseAdapter. This adapter implements two listeners, defined in the *defineListeners* method, to turn on/off ***Rules*** and run ***Scenes***. Considering the elderly needs, a vibration was added to increase user awareness while interacting with the Mobile App. For this purpose, both listeners, when triggered, produces a vibration of 0.4 seconds.

The Listener from each radioButton is implemented using the *onSimpleClickListener* class.

The modules block use defined models like Rule, Scene, and Trigger. These models are classes that represent the ***Rules***, ***Scenes*** and ***Triggers***, respectively, received from the Web server.

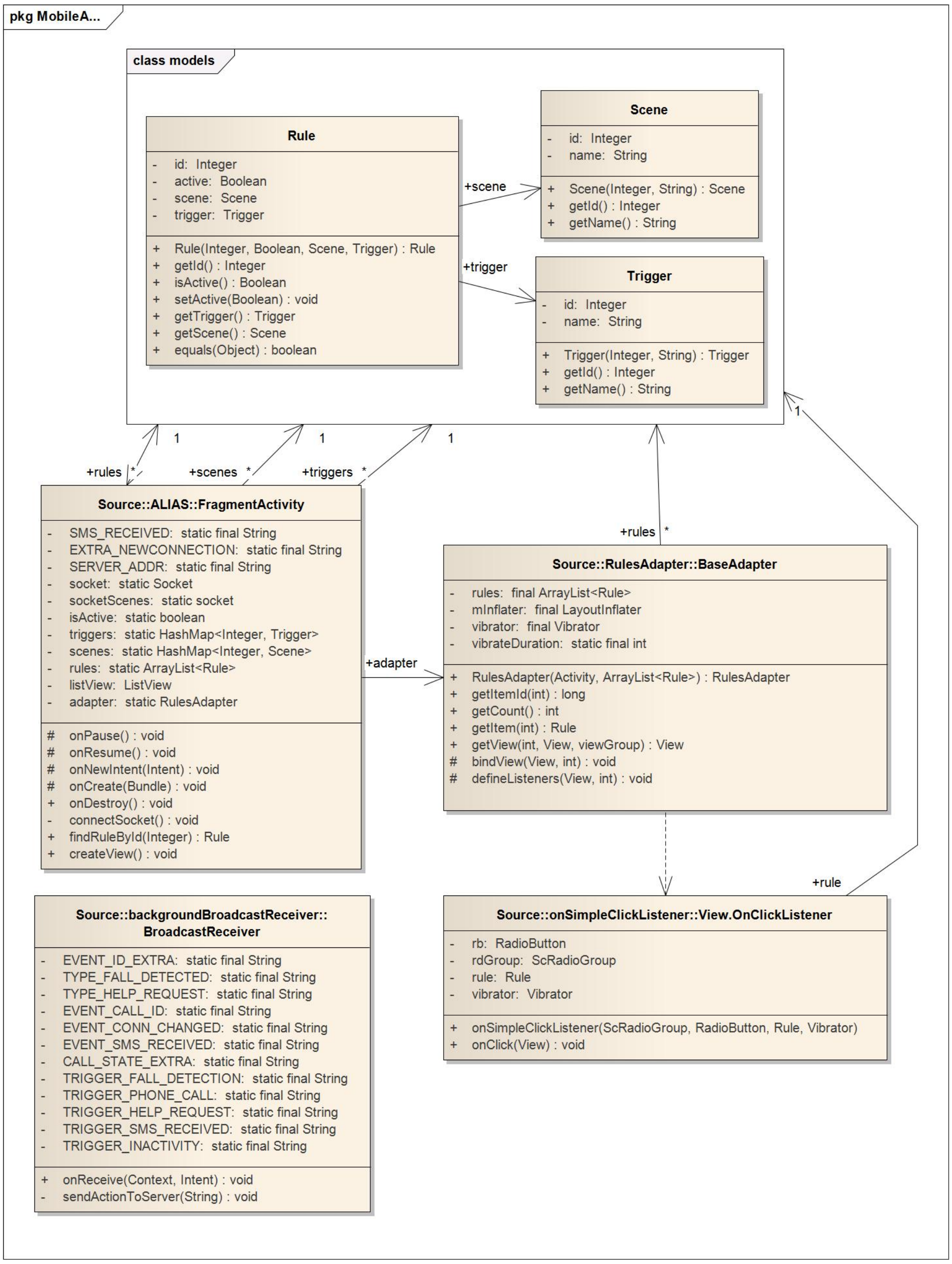

Figure 5.11: Mobile Application Architecture.

The *backgroundBroadcastReceiver* module is a receiver for broadcast communications from Android events like SMS reception or connectivity changed and SmartCompanion events like fall detection, phone call reception, help request or inactivity. Upon reception of these messages, originated on the phone or on the SmartCompanion Application, the *backgroundBroadcastReceiver* communicates the event to the Web server, which will run the respective actions needed.

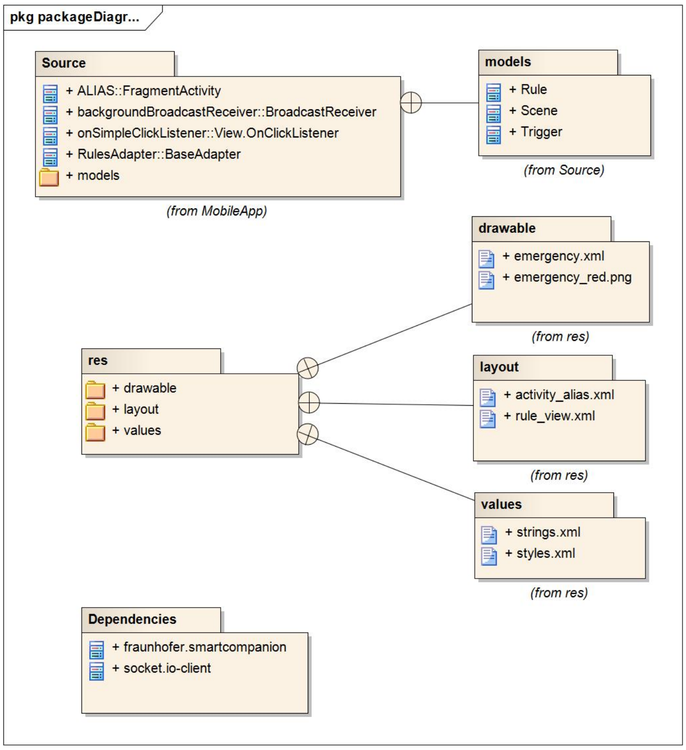

Figure 5.12: Package Diagram of the Mobile App

Figure 5.12 represents the package diagram for the Mobile App, where the source folder is composed by Java code files and by the subfolder models that have the three objects that are received from the Web server. In the resources folder are the drawable folder with the emergency button selector and icon, the layout folder with layouts for the main activity and for the BaseAdapter, and the values folder with strings and styles.

The library SmartCompanion from Fraunhofer Portugal and socket.io-client are the two main dependencies of the Mobile Application.

Chapter 6

Results

In this chapter the applications developed will be shown as final results.

In order to test the health benefits of the final system, several volunteers are required. Those volunteers should be available to remain in a test environment (inside house, under the effect of Philips Lights and possibly away from any external source of light) for a long period of time (at least 24h to manipulate the user's circadian rhythm).

Because of the context's hard nature to perform tests and validating results, tests beyond system's operation weren't done.

6.1 Web Server

Since the Web server is a service provider, there isn't a lot to show. However, since the Web server is also listening for HTTP requests, it is possible to call several requests. Figure 6.1 shows some examples.

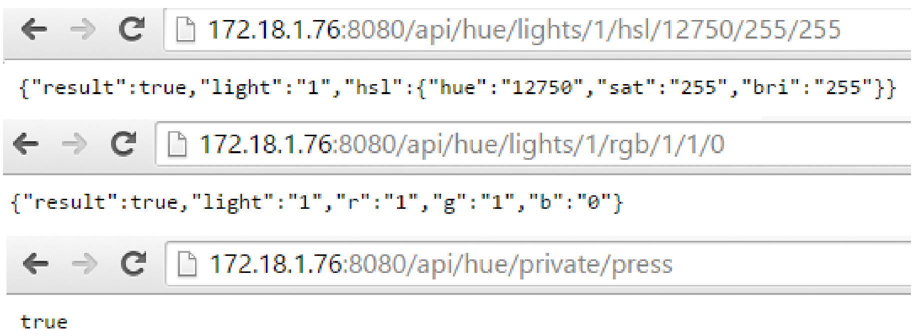

Figure 6.1: Web server HTTP requests

The first request in Figure 6.1, sends a command to change Hue, Saturation and Brightness of Light 1.

The second request, orders a red green blue representation of the color. This feature isn't used in the real environment when we are manipulating lights. An RGB color picker wouldn't be as accurate as an HSL color picker since the black component of the color is impossible to reproduce.

The third request makes part of the private features of the Web server. This request allows to simulate a press of a physical button of the Hue Bridge. Useful for attaching new devices or add permissions to external applications.

6.2 Web Application

The interaction with the Web Application is composed by six web pages. Five of them are present on a navigation tab shown in Figure 6.2. The sixth page is the page to create new ***Scenes***.

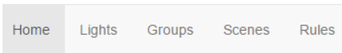

Figure 6.2: Navigation Tab

The Home page, shown in Figure 6.3, is composed by two buttons: SOS button and Search Lights button. The SOS button will trigger the SOS ***Rule***, and the Search Lights button will order the Bridge to scan and communicate to all nearby light bulbs to find newly installed light bulbs.

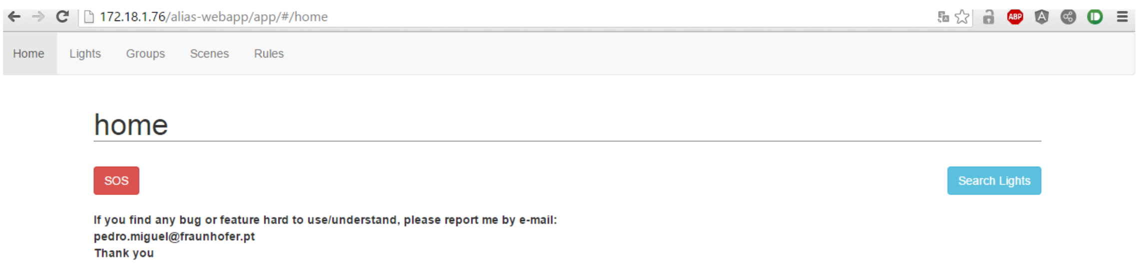

Figure 6.3: Home page

On the Lights page is possible to see and manipulate all lights attached to the Bridge. In this page the user can interact in real time with the lights, changing all their parameters like on/off status, Hue, Saturation, Brightness, Color temperature, Alertness (blink once or fifteen times) and change the Light name. All of those manipulations are communicated to all Web Applications in order to update their UI automatically.

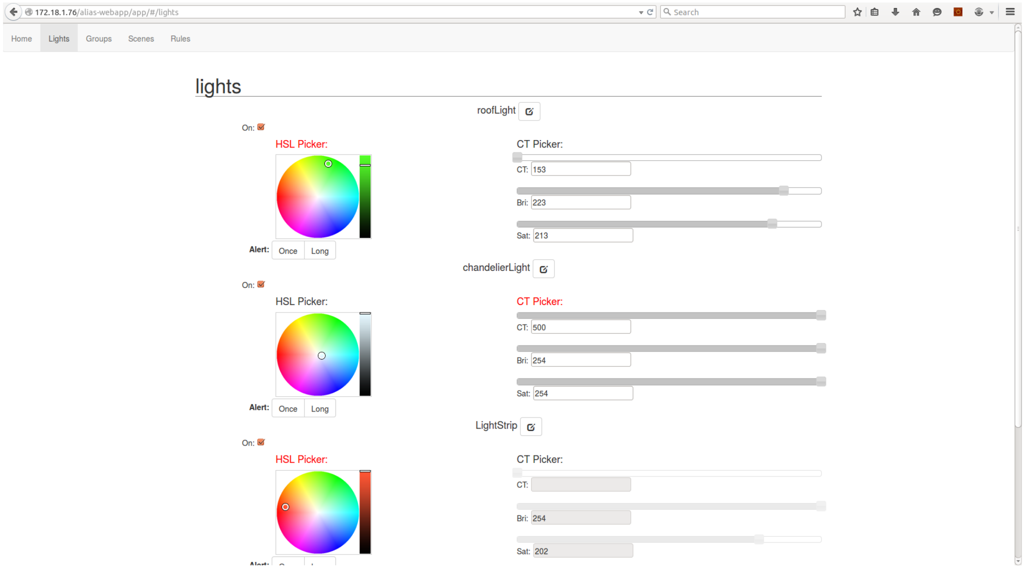

Figure 6.4: Lights page

When a specific light that once was present on the Bridge is no longer reachable, probably because the light was switched off directly on the power supply or the light is out-of-range of Zigbee network, the UI for that light is presented as blocked (see Figure 6.5).

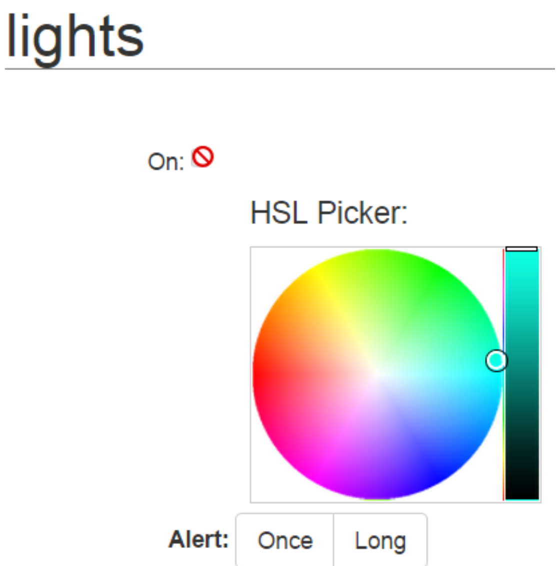

Figure 6.5: Partial UI of an unreachable light

On the Groups tab is possible to see, create, delete and edit ***Groups***. Each ***Group*** has a name and a set of Lights.

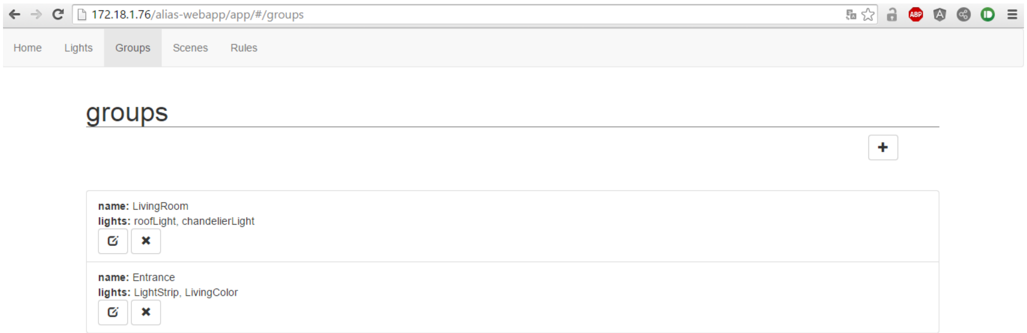

Figure 6.6: Groups page

In order to create, delete or edit a ***Group***, the user needs to press the icons for that effect. In the case of add or edit ***Groups***, a modal window will appear to allow the user to input the ***Group*** name and the Lights for that ***Group***, as shown in Figure 6.7.

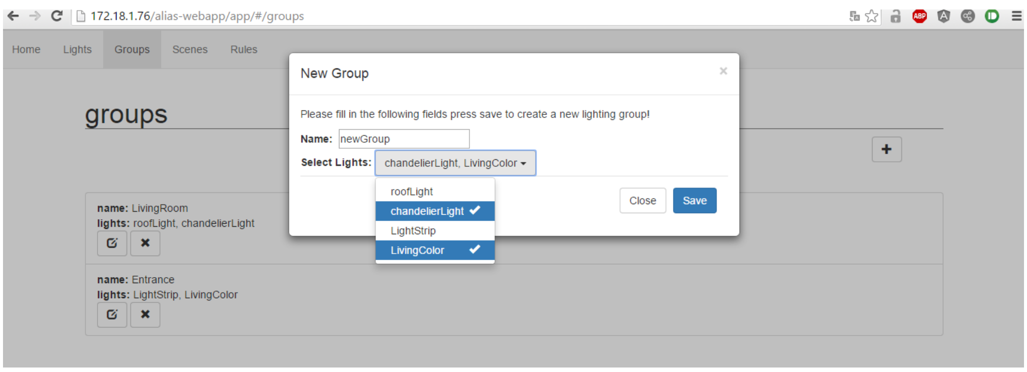

Figure 6.7: Modal page to create a new ***Group***. Similar modal for edit ***Group***

On the Scenes tab, is possible to list, create, delete and run ***Scenes***. To create, delete and run ***Scenes***, is necessary to click the respective buttons, as seen in Figure 6.8.

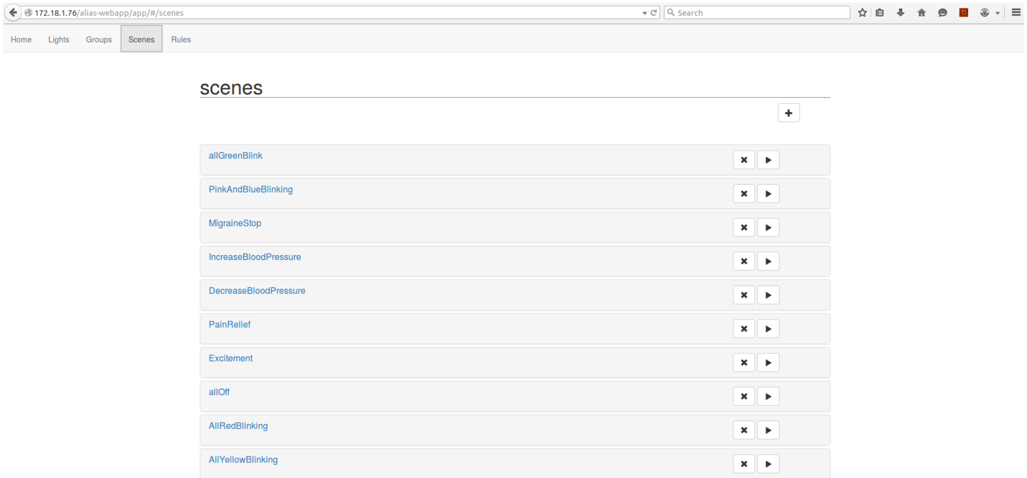

Figure 6.8: Scenes page

When the user presses the add button, the *addScene* page is launched. The reason this page isn't a modal like the other interfaces for adding new Models, is because this specific interface is complex and extensive, as shown in Figure 6.9.

To create a new ***Scene***, the user should first enter the name for the new ***Scene***. Then, to specify what the scene looks like, the user can use several Lights and ***Groups***.

Pressing on the Light/***Group*** name, will expand the interface for that specific model (Light or ***Group***). When the user is satisfied with the state of that model, he should press the pin button to save that state. If the user wants to change its state, he can just change on the UI of that model and press again the pin button. The light state will be updated.

When everything is ready, the Save Scene button should be clicked and if everything is OK, the user will be redirected to the ***Scenes*** page. If any error is detected, a message will be shown.

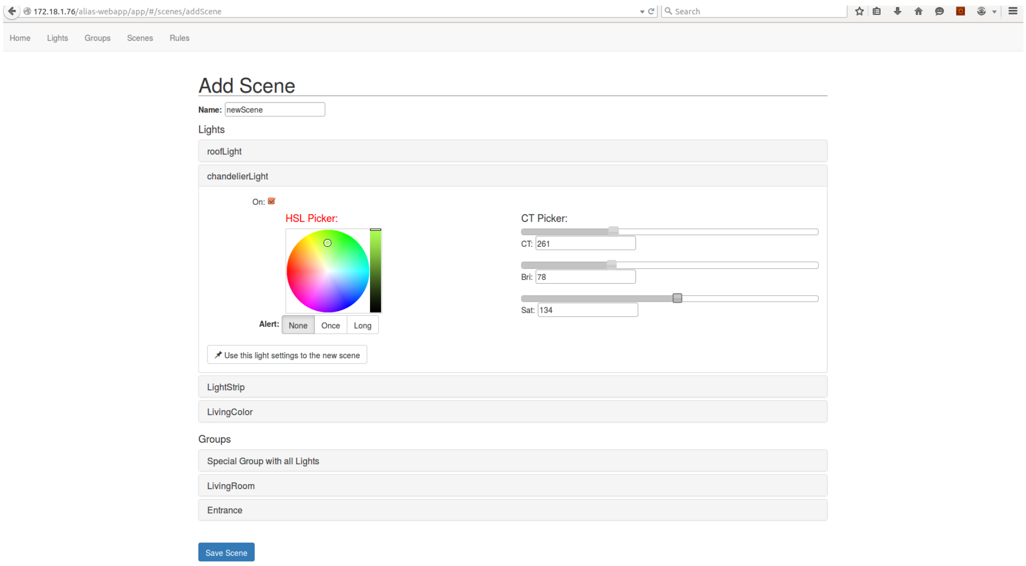

Figure 6.9: Add Scene page

When any user runs a ***Scene***, from the Web Application or from the Mobile Application, an indication like the one in Figure 6.10 is displayed on the Scenes page of the Web Application.

Figure 6.10: Color indicates that the ***Scene*** *MigraineStop* is running

On the Rules tab, Figure 6.11, all the ***Rules*** are visible and available to be turned on/off or deleted. The Circadian Rhythm has a highlighted position not only by its importance, but also because it can't be deleted. Additionally, there is a button to create new ***Rules***.

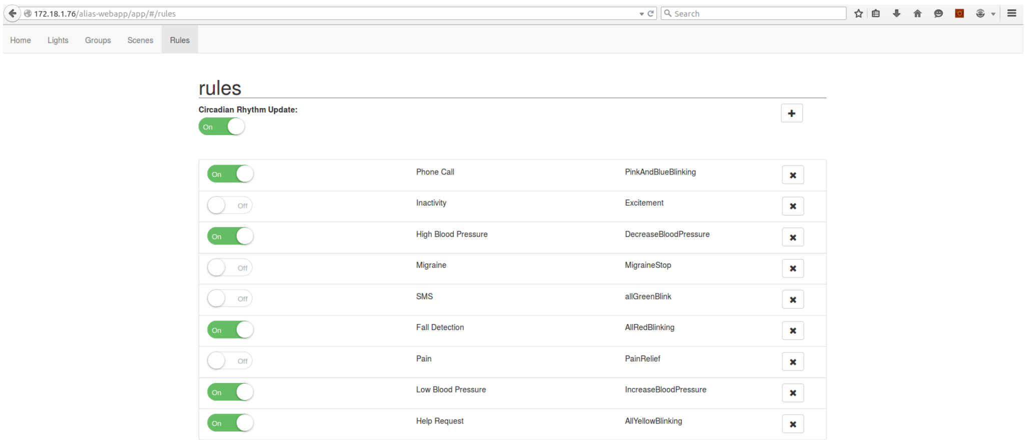

Figure 6.11: Rules page

When the user presses the button to add a new ***Rule***, a modal pops up. On this modal it is possible to see all ***Triggers*** and ***Scenes***, and select a ***Scene*** to run with a specific ***Trigger***.

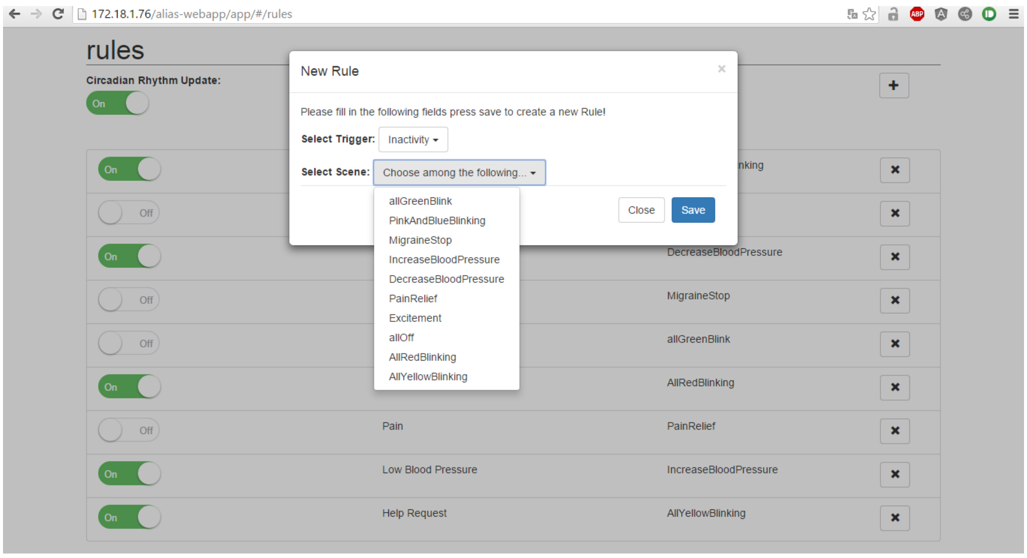

Figure 6.12: Modal page to add a new ***Rule***

In order to inform the user about his actions or other user's actions, the Web Application can display several messages, as shown in Figure 6.13.

Red messages inform the user about some errors that happened on his inputs. Messages with green background are successful messages and inform the user about the success of his actions. The messages with blue background are informative messages and have the intention to inform the user, in real time, about the creation, removal and modification actions from other users.

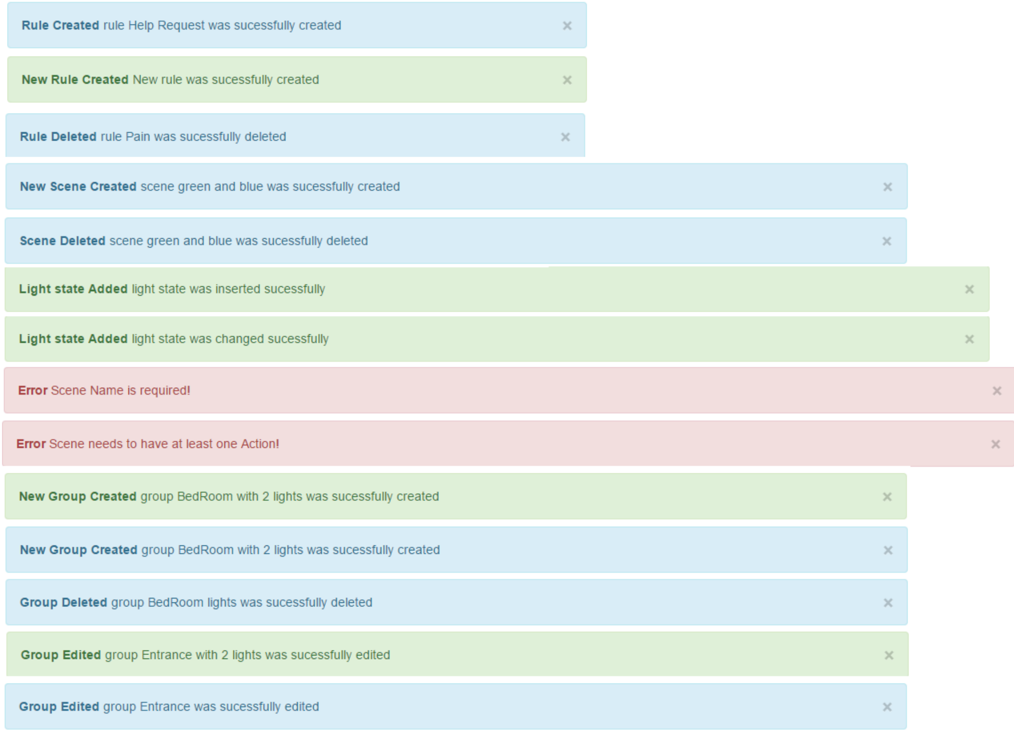

Figure 6.13: List of possible messages during Web Application interaction

6.3 Mobile App

In the Mobile Application, it is possible to see and turn on/off all ***Rules***, run the ***Scene*** from a specific ***Rule*** and call the SOS ***Trigger***.

The UI visible in Figure 6.14 was developed using the SmartCompanion's library which has special requirements to fit the elderly's constraints and requirements.

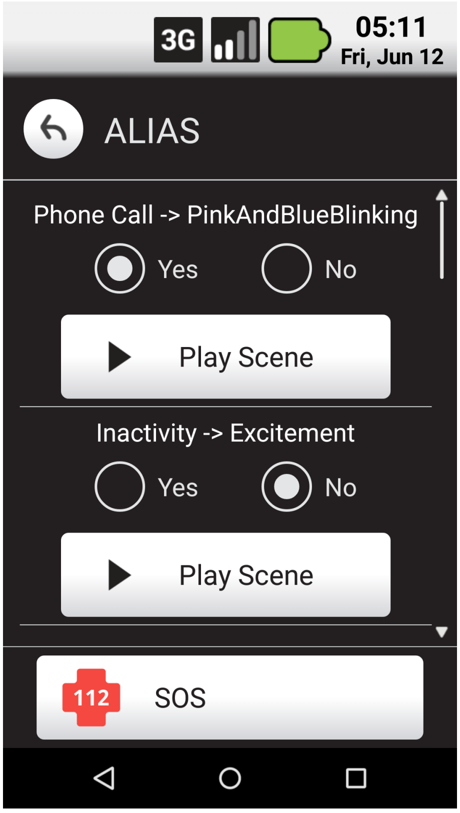

Figure 6.14: Interface of the Mobile Application

Other features are present on the Mobile Application that aren't visible on the UI, for example its interaction with SmartCompanion. On Fraunhofer's SmartCompanion application, is possible to request help to the emergency contact, detect falls, detect incoming calls and detect inactivity from the elderly. Those events are broadcasted and the Mobile Application is listening for those broadcasts. When the broadcasts are received by the Mobile Application, a communication is sent to the Web server in order to reproduce the respective ***Scenes***.

The Mobile Application is listening to other broadcasts beyond SmartCompanion's, like connectivity change and SMS reception. The App uses the connectivity change in order to reconnect to the Web server (if new connection) or to clean the list of ***Rules*** (on connection loss, see Figure 6.15);

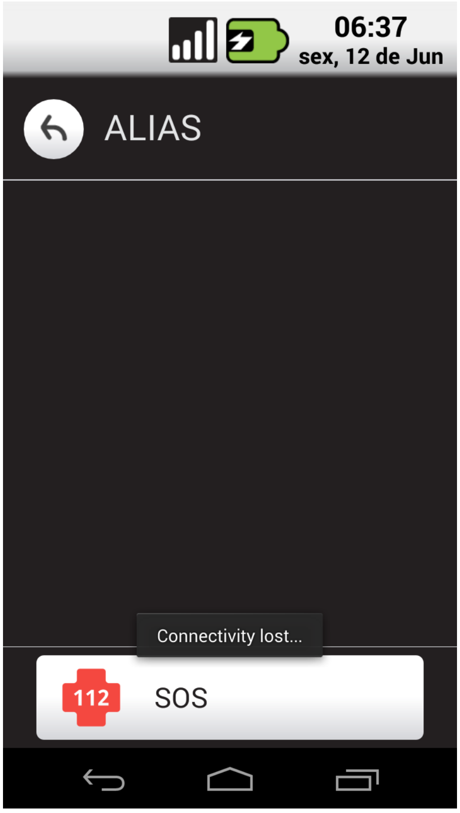

Figure 6.15: Interface of the Mobile Application on connection loss.

6.4 System Interaction

Since the entire system is bonded (by the Web server) and continuously communicating via Socket, then if any client Application asks the Web server to update any model object (Light, ***Group***, ***Scene*** or ***Rule***), all other client applications will be notified about the object's modification (Figure 6.16).

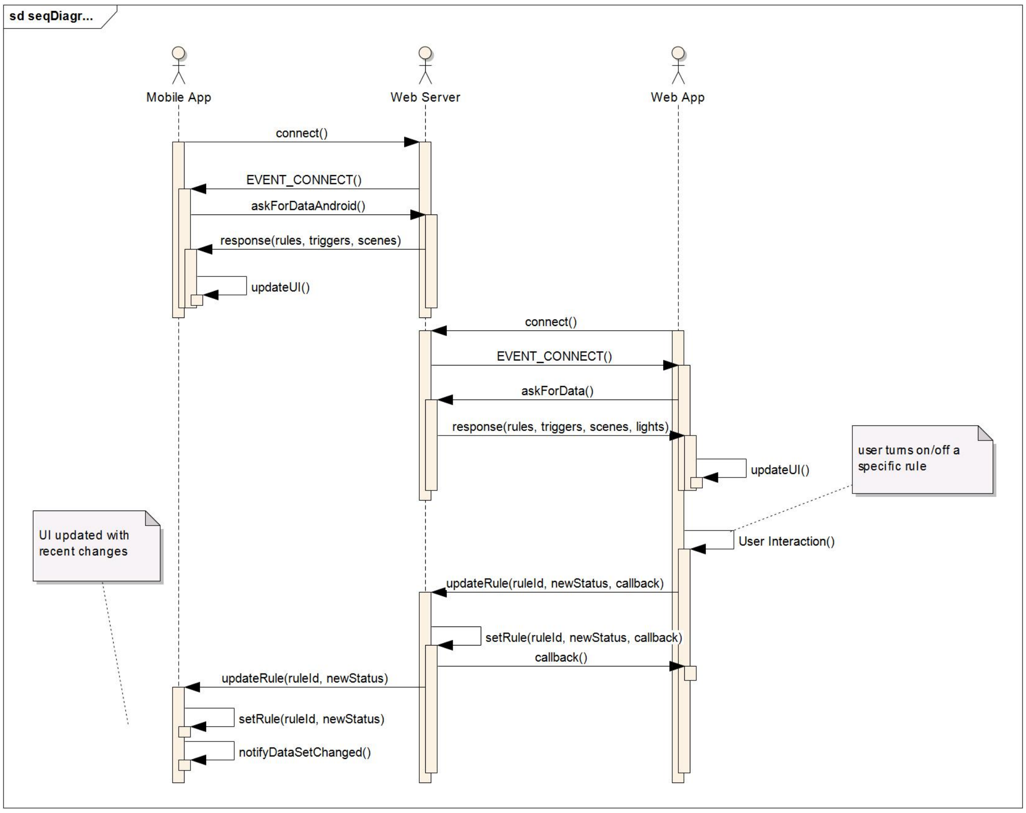

Figure 6.16: Example of System's behavior on User Interaction.

The result of this interaction can be seen on the Figures 6.17 and 6.18, that shows two Web Applications (one on the background monitor and the other on a laptop) and two Mobile Applications (one virtual device on the background monitor and one on an Android smartphone). All those client Applications are opened, running and connected to the Web server.

Figure 6.17 shows the UIs before the user interaction. In this case, the interaction was to turn off, on the smartphone, the ***Rule*** that produces the ***Scene*** *PinkAndBlue-Blinking* when the ***Trigger*** *Phone Call* is detected.

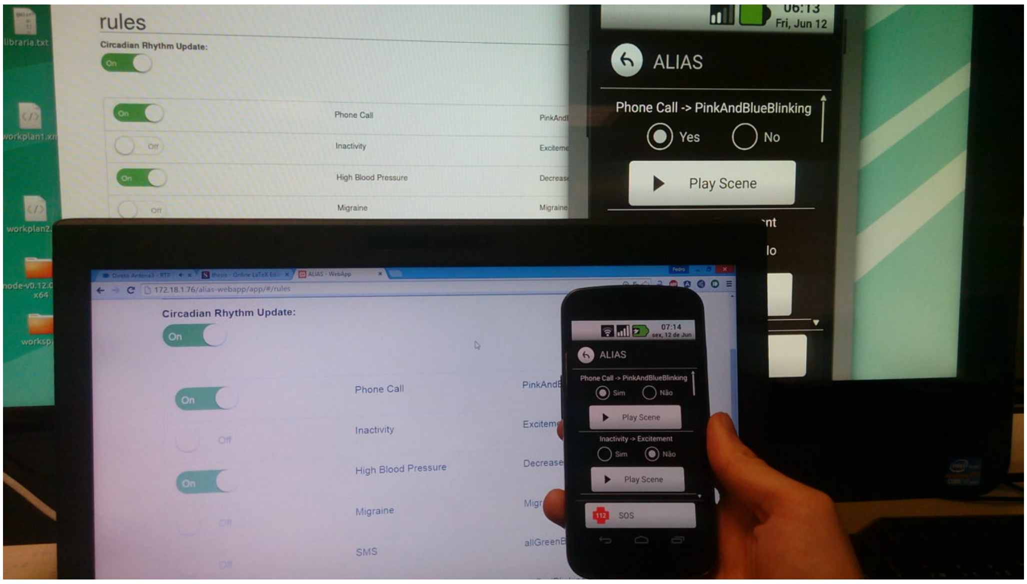

Figure 6.17: Interfaces before User Interaction (turn off 1st ***Rule***)

In Figure 6.18 the state of all client Applications after the user interaction is shown. It is visible that all of them were automatically updated.

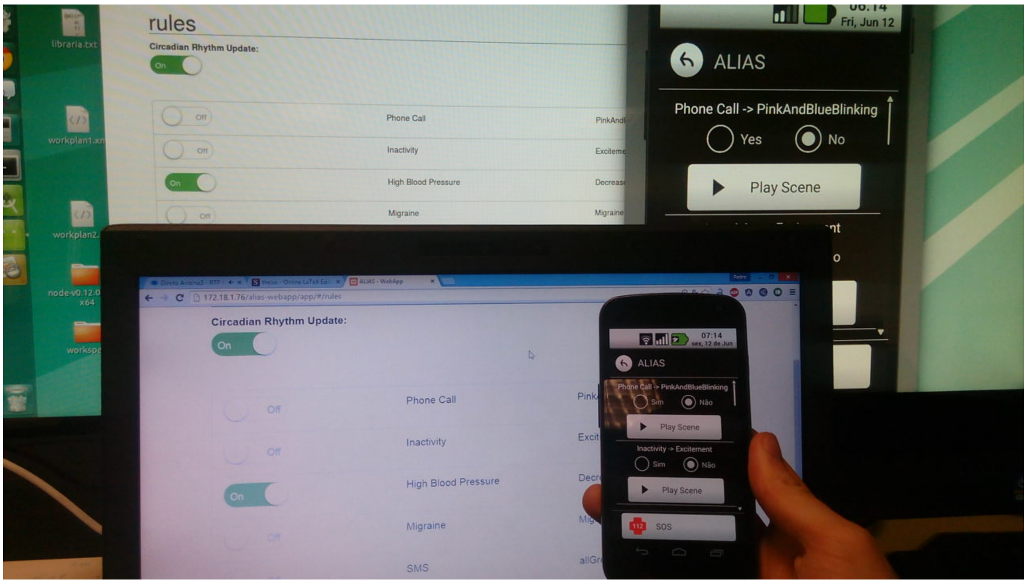

Figure 6.18: Interfaces after User Interaction (1st ***Rule*** turned off).

On Figure 6.19, the incoming call situation was reproduced. The Mobile Application was running on the smartphone that has the SmartCompanion launcher (Android device on the right) and it receives a phone call (from the Android device on the left).

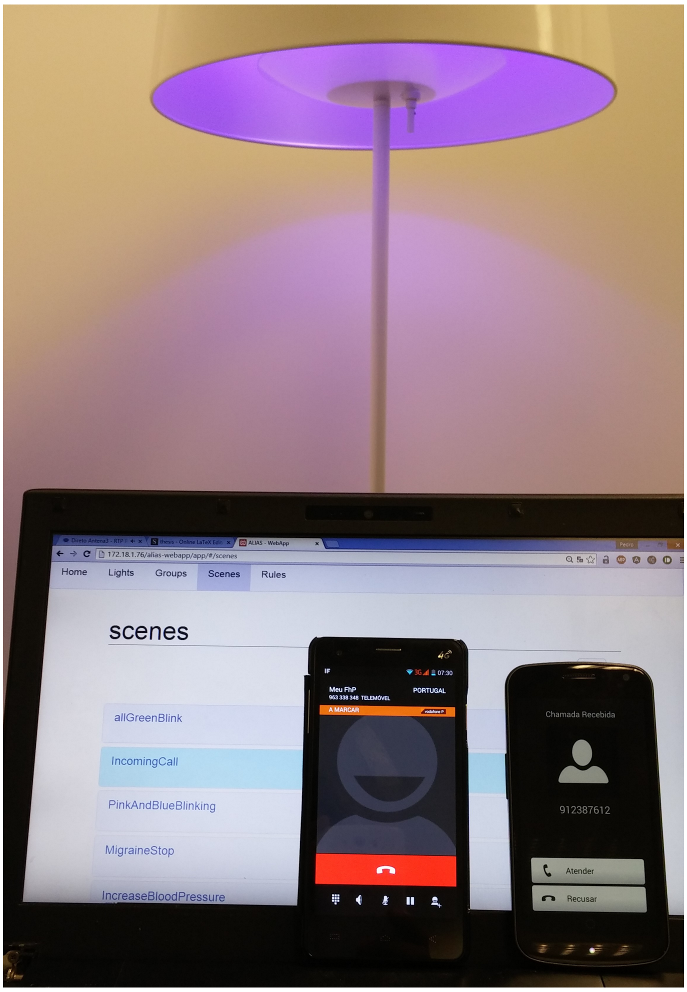

Figure 6.19: Example of System behavior: Incoming phone call.

The reception of the phone call is detected by the Mobile Application which will communicate to the Web server to run the respective ***Scene***(labeled as *IncomingCall* and reproducing purple on the light bulb presented). The Web server also broadcasts which specific ***Scene*** is running and in this way the Web Applications can update their UI to inform other users.

In Figure 6.20 we see a similar situation, but with a different ***Trigger*** and reproduction of a different ***Scene***. In this case the ***Trigger*** is the reception of an SMS and the ***Scene*** is labeled as *SMS received* and reproduces a yellow light.

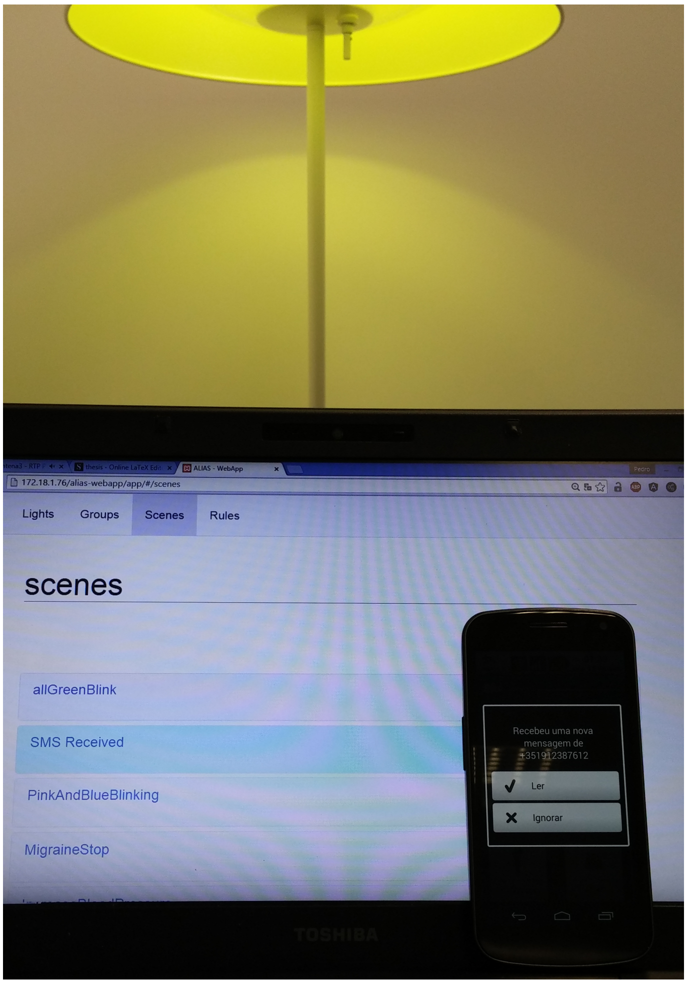

Figure 6.20: Example of System behaviour: SMS reception.

6.5 Remote API

The item 2 of list 4.1-Constraints exposes the problem of having available solely a local API.

At the Philips Hue FAQ page, is referred that it is planned to release a remote API in the future [mee15], however an unofficial method to control the lights remotely was released. The method is to fake an Official iOS App in order to get a private access token. This access token allows requests to be sent remotely to the bridge, on behalf of the iOS App. The method is explained at Shi's Blog [Shi13].

In order to overcome the constraint referred, this solution was implemented on a completely new code branch. This branch serves to test the solution and also to visualize the possibilities for the system if Philips Hue releases an official remote API. The content of this branch, because is unsupported, unofficial and exploits the Philips Hue system, should just be used for testing purposes and never on a real environment, or commercialized.

With this solution, it is possible to control remotely the Hue lights. However, the remote API is very limited and unreliable (only accepts one GET request and all POST requests return 200 OK). It should be also referred that the requests take 10 to 20 seconds to get responded (for GET requests) and to take effect (for POST requests).

6.6 Development and environment

The Bridge (Figure 6.21) is powered by a power plug and connected on *Fraunhofer Portugal*'s network.

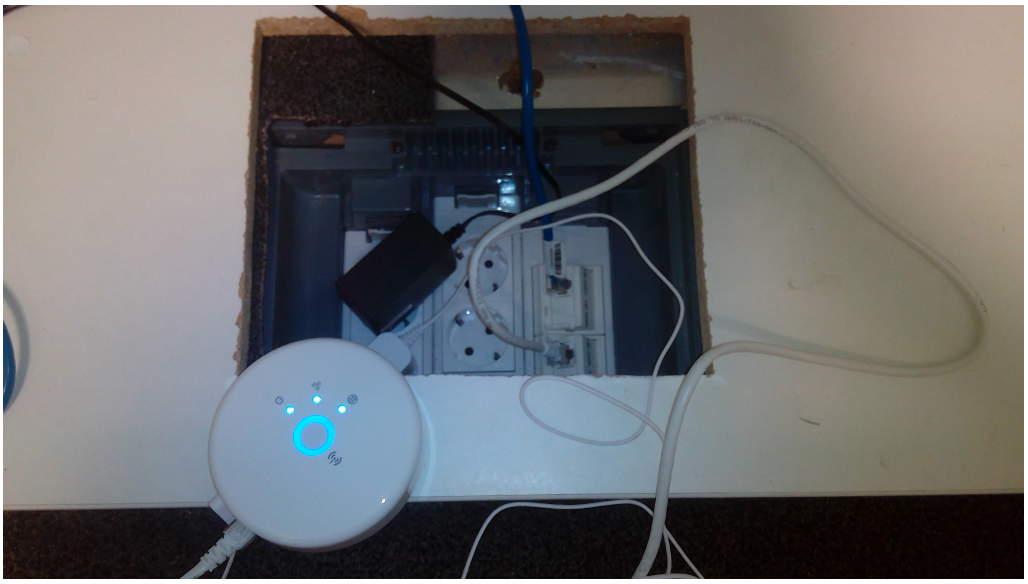

Figure 6.21: Bridge installed on *Fraunhofer Portugal*'s facilities.

Figures 6.22 and 6.23 show the environment used to test the system developed. The environment is composed by two Philips Hue E27 light bulbs (red and pink on Figure 6.23), one Hue Iris (blue on Figure 6.23) and one LightStrip (green on Figure 6.23).

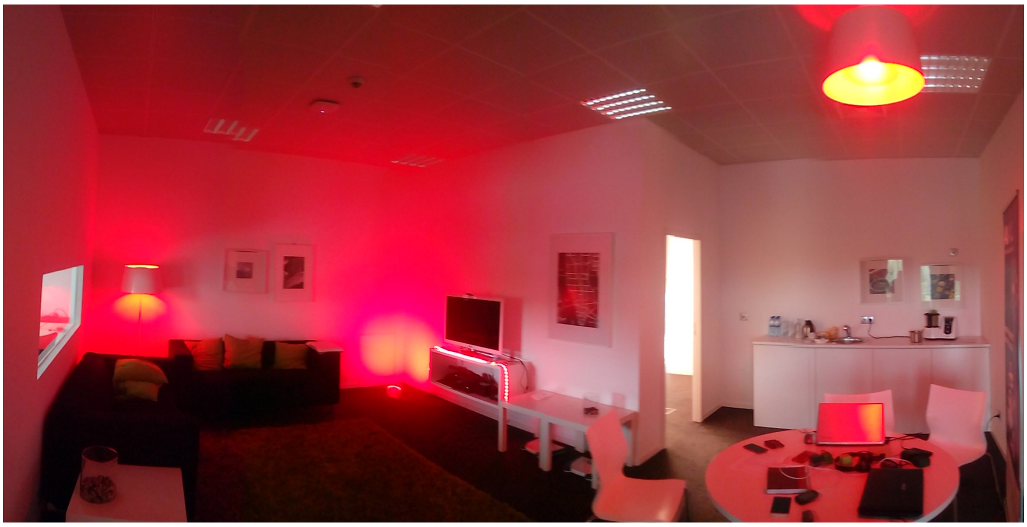

Figure 6.22: Testing space with fully immerse environment.

Figure 6.23: Testing space with multiple colors.

Chapter 7

Conclusions

In this chapter the conclusions from this project are discussed.

7.1 Objectives fulfilment

All the initial objectives for mounting, developing and controlling a test illumination system have been accomplished. All the four planned modules were successfully developed: Android Application oriented for the elderly, Web Application aimed for the caregiver, Web server for interaction and link between the client applications and the Philips Hue System, including a Database for storing all necessary data.

The developed system fulfills the main goal which is to provide a personalized wireless ambient lighting for assisted environments, using the lights for health and notification purposes. The lights act automatically to promote circadian rhythm, using several colors to provide a comfortable, soothing and self-healing environment, and react to several external events like fall detection, help requests or SMS and phone call reception. Therefore, the final results were very satisfactory.

An important information to take note is that the hue values that should be applied at each time of day are estimated, since it wasn't found any reference that links the specific hue values to the specific times of the day.

The contribution of this work is the promotion of a healthier, safer and interactive environment not only for the elderly, but also for everyone. Some of the methodologies used in this project can be applied to a wide range of places and scenarios, like workplaces or public illumination. This work encourages the usage and development of lighting in a smarter and deliberated manner.

This work also aims to help further investigation about the lighting effects on living beings, by supplying a system able to support many test environments.

7.2 Future work

Some future work can be done in order to further improve the system developed.

On the Web Application, the user-interface and consequently the user-interaction can be improved, for example, implementing a ***Scene*** editor and viewer or even an access control with login/logout access, particularly if the system is using remote accesses.

The Mobile Application can be improved, with the integration and usage of external sensors like blood pressure in order to automatically update the lights according to each specific scenario (low/high blood pressure, for instance). Another future improvement in the Mobile Application is the integration of medication reminders used in the SmartCompanion Launcher.

Another possibility would be to improve the Web server, allowing the existence of user accounts on the Database, implementing the necessary CRUD operations (for the Web application access control). Also, it could be possible to allow a registration of the mobile devices that use the Mobile App. This registration would be used to separate ***Rules*** by mobile users. This would be useful for customization in environments with several elders. More future improvements to the Web server are dependent of the Philips Hue API, regarding a Remote API and the *Pointsymbol* feature. If Philips Hue releases an official remote API, an adaptation of the Web server API module should be done to support it. The *Pointsymbol* is a parameter present on Philips Hue's API that isn't, at the present time, supported. This parameter contains a set of color sequences that updates the light or groups of light for a short period of time. When the sequence is done, the light or groups of lights returns to the previous state. This feature would be useful for notification purposes because the blinks can be faster and the light's status after the notification would remain the same as previously.

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